MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

SEPTEMBER•OCTOBER 1998

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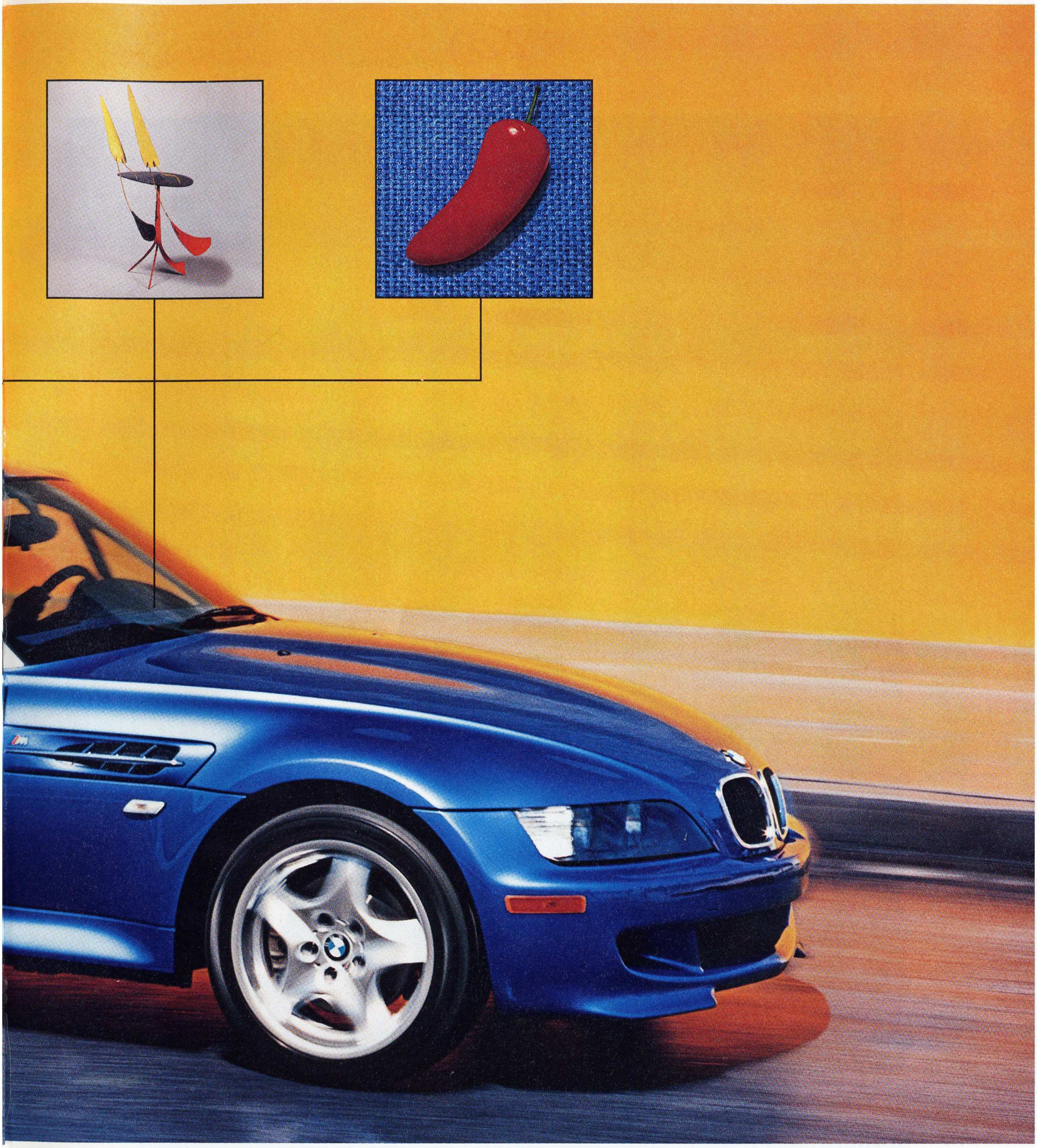

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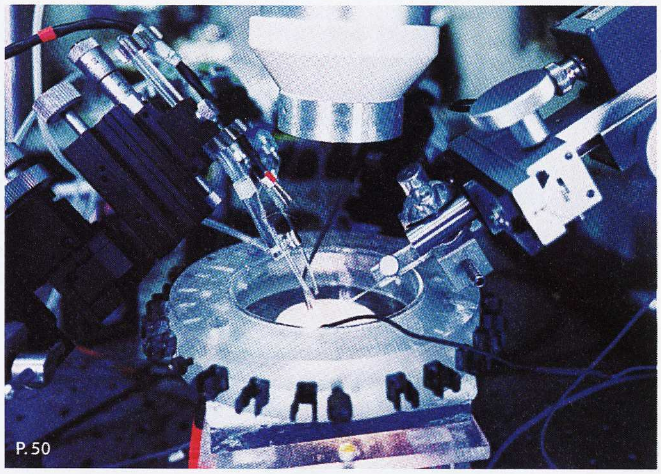

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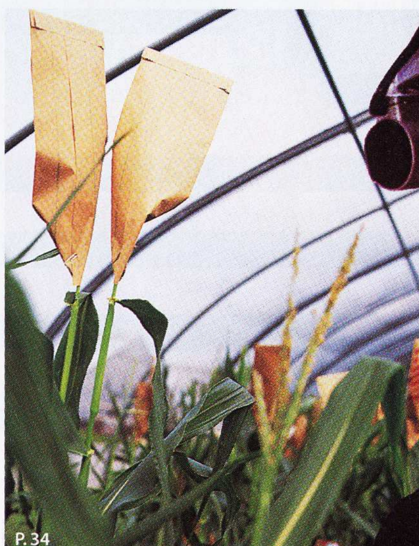

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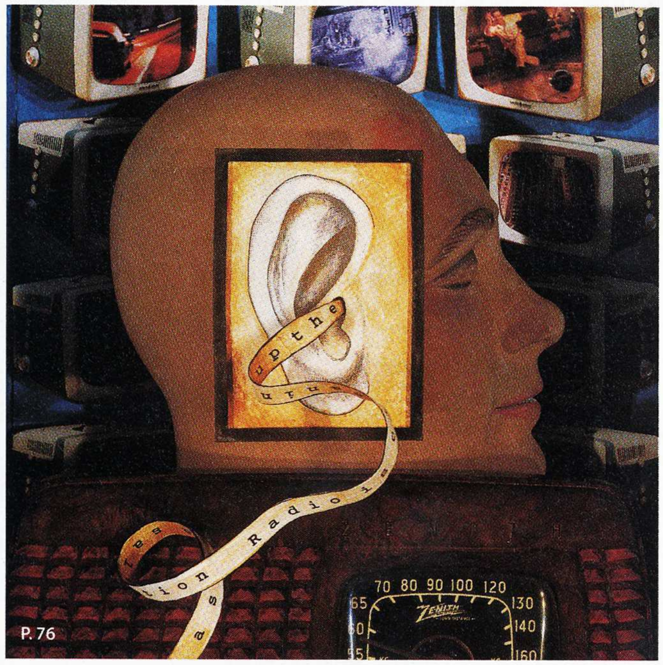
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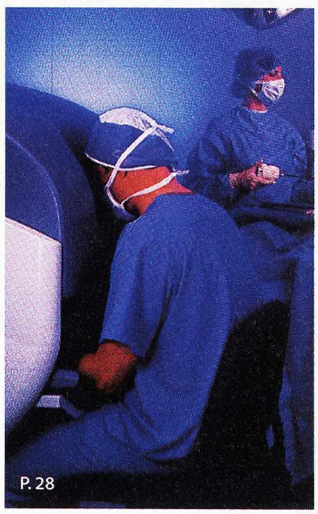
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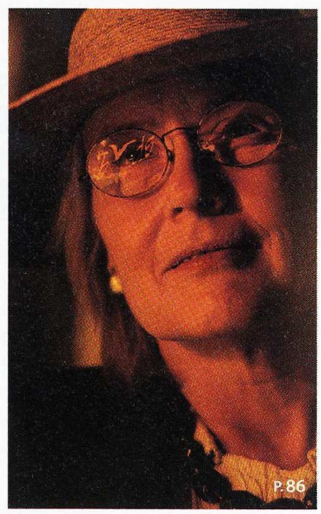
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Matters of Size

WHEN WE INTRODUCED THE NEW TECHNOLOGY REVIEW, WE PROMISED WE WOULD cover the entire "innovation system" of the United States and the rest of the industrial world. And we've begun to do that—giving you an inside view of university research labs, venture capital firms, high-tech startups and major technology companies. Within the overall innovation system, the glamor part is the startups. Magazines like *Wired*, *Red Herring* and *Upside* zero in on companies started by 20-year-olds working 18 hours a day so they can sell their startup to Microsoft by the time they're 22. It's understandable that these ventures get so much attention. They're romantic, and unique: No other country has a climate so favorable to entrepreneurship.

But a look beneath the surface of our system shows that innovation is not confined to the double-latte set. In order to succeed, major technological corporations must also create internal environments as white-hot as anything you might find in a Seattle garage.

To highlight the combined contributions of startups and industrial giants in our innovation system, we've chosen to pair two intriguing articles in our first *Technology Review* Special Report: Innovation Large and Small. Contributing Writer Robert Buderi takes you behind the scenes at the "new" Bell Labs. Bell Labs was for many years the crown jewel of American industrial R&D. Powered by a "research tax" on telephone service that was made possible by AT&T's monopoly status, the labs allowed elite basic researchers to pursue fundamental investigations far removed from the goal of improving telephone service.

But times change. Following the breakup of AT&T in 1984, Bell Labs became a component of a new company called Lucent Technologies. Lucent shrank the lab and focused its work on the bottom line—provoking outrage from the research community and prompting the departure of some talented investigators, who found more congenial homes at universities. Buderi's reporting shows that despite these protests basic research at Bell Labs may be healthier than ever.

The heart of Buderi's tale is a large institution that has flourished because of the contributions of many individuals. In our companion piece, Simson Garfinkel tells the story of a scrappy company called Dragon Systems that was built by one married couple: Jim and Janet Baker. The Bakers are researcher-entrepreneurs who met at their computer screens. Their lives and professional interests are inextricably intertwined, and their company is a direct reflection of their personalities. In contrast to some of the flash-in-the-pan startups we see today, the Bakers worked for decades at the cutting edge of speech recognition, building a company and numerous products that today compete head-to-head with IBM in the marketplace.

Taken together, these penetrating articles offer a look at two dimensions of our innovation system: the very large and the very small. In future issues, we'll be covering the rest of the innovation system. Because that's our mandate. Innovation.

—John Benditt

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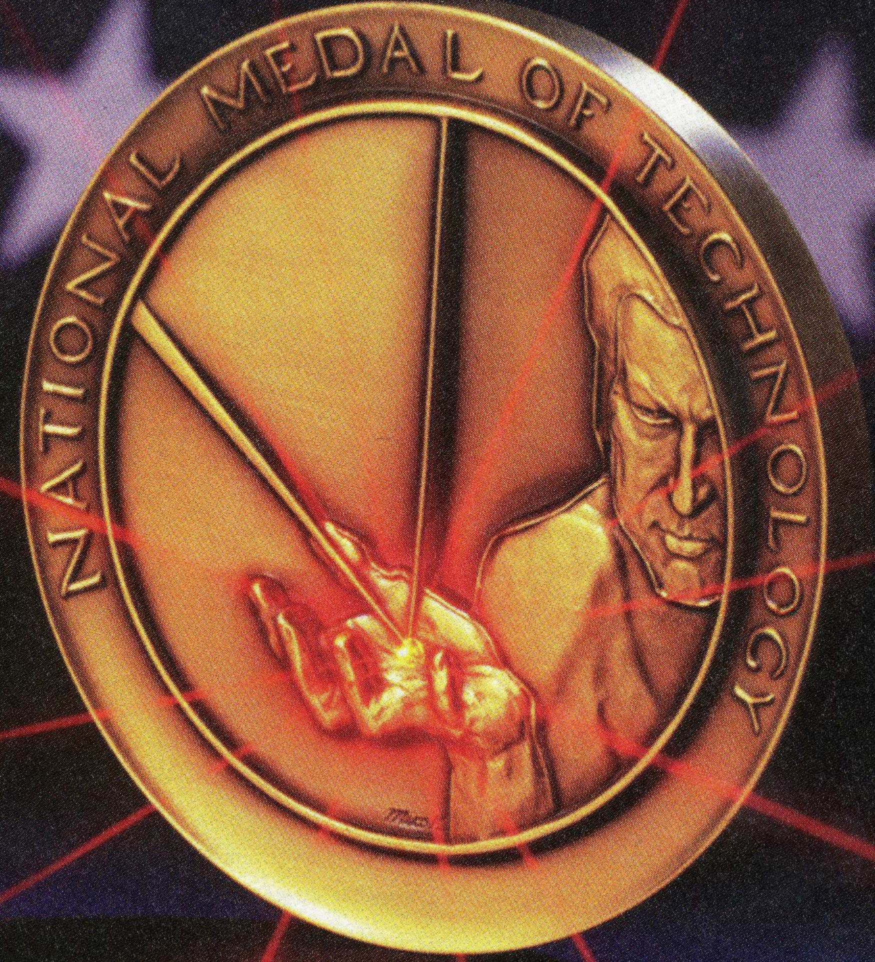
Announcing
The National Medal of Technology
1999 Call for Nominations



The American spirit of innovation is the heart of our nation's economic strength and prosperity. As we approach the turn of the century, we are challenged to continue expanding the frontiers of knowledge to maintain global competitiveness and an ever improving quality of life. The National Medal of Technology recognizes American innovators whose vision, intellect, creativity and sheer determination have had profound and lasting impact on our economy and way of living.

Established by Congress in 1980, the President of the United States awards the National Medal of Technology each year to our nation's leading innovators. If you know of a candidate who has made an outstanding contribution in technology, send for a nomination packet now. The deadline for submissions is December 1, 1998.

1999 Nomination packets can be obtained from:
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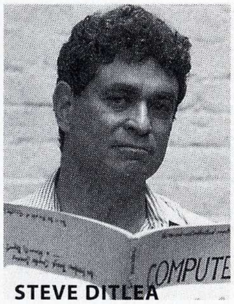
Although the new *TR* is only three issues old, we're pleased that we can already claim **Robert Buderi** and **Simson Garfinkel** as regular contributors. We paired feature stories by these two senior journalists to create this issue's cover story—a Special Report on Innovation Large and Small. Buderi leads off with a tale of revitalized research at the flagship of U.S. industrial R&D: Bell Labs. Garfinkel follows with the story of how an entrepreneurial outfit named Dragon Systems became the leader in speech recognition software. | As we develop a circle of regular writers, we're also reaching out and bringing new voices into our pages. In "Ted Nelson's Big Step," first-time *TR* contributor **Steve Ditlea** sketches an entertaining portrait of an iconoclastic computer visionary and his newly released software, ZigZag. Ditlea, who met Nelson in 1983, has written about him over the years for *Omni*, *PC Computing* and *CyberTimes*. "In my two decades of covering the computer industry," says Ditlea, "Nelson is the only genius I have ever met. He's certifiable!" | Nelson may have competition from another high-level intellect in our pages: Jakob Nielsen. **William Allstetter** says he buttonholed Nielsen for a Q&A (starting on p. 72) after hearing that this Sun Microsystems engineer was "the smartest man on the Web." Allstetter, also a new contributor to *TR*, just completed a five-year stint with Facts on File and is producing a science and technology almanac for Oryx Press. | During production of our first two issues, *TR* senior editor **David Rotman** labored behind the scenes, helping shape some of *TR*'s best features such as "The Troubled Hunt for the Ultimate Cell" (July/August). In this issue, he steps out from behind the curtain with "Biotech's Next Harvest," a peek at the coming revolution in agricultural biotechnology and its unexpected champions: chemical companies. | The new breeds of genetically-engineered plants are already having an impact in places like Great Falls, Mont., where wheat-farmer and freelance science journalist **Carol Potera** lives. But Potera's got more up her sleeve than seed husks as she takes on another area of rapid change in biotech: vaccine delivery. Potera, whose award-winning coverage of health issues has appeared in magazines such as *Science* and *Men's Health*, reports that painful needle-sticks could soon be a thing of the past. | *TR*'s feature stories document the blistering pace of technological innovation—which inspires both utopian hype and predictions of doom. **David Shenk**, a founding member of the burgeoning "Technorealism" movement (http://www.technorealism.org), seeks a more measured view. An artful writer whose work has appeared in *The New Yorker*, Shenk is the author of *Data Smog: Surviving the Information Glut* (now out in paperback from HarperCollins), and is also an occasional commentator for National Public Radio's "All Things Considered." He shares his fondness for the gentle medium in this month's Viewpoint. TR



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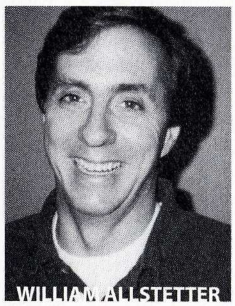
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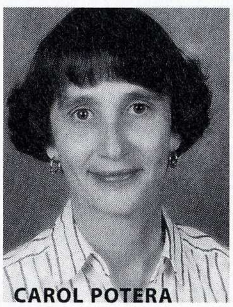
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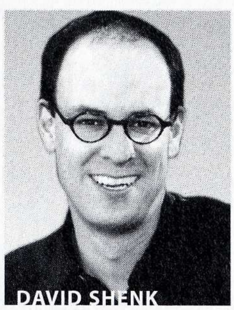
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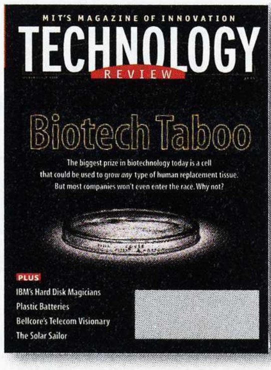
"Regalado's excellent article will help readers understand the clinical benefits from this important area of science."

Stem Cell Controversy

IN "THE TROUBLED HUNT FOR THE Ultimate Cell" (*TR* July/August 1998), Antonio Regalado addresses a few of the ethical concerns surrounding human embryonic stem cell research. He neglected to mention, however, one ethical and moral concern that is of paramount importance—whether we should experiment with these human lives at all.

In the pursuit of these elusive cells, researchers are destroying living human embryos who need only time and nourishment to grow to be adults. Aborted babies also have these stem cells. Should we undertake such research at the expense of human life, just because we can? The answer is no.



Many would justify the use of the embryonic and fetal tissue by pointing to the "good" that comes of it. This is the same argument that the Chinese make when they defend their practice of harvesting the organs of executed prisoners. The Chinese say that these organs save some lives, but we condemn these actions as unethical. Likewise, we should be disgusted with the harvesting of the bodies of unborn children whose lives have been taken by abortion.

LAURA A. ECHEVARRIA
Director of Media Relations
National Right to Life Committee Inc.
Washington, DC

BECAUSE I HAVE JUST COMPLETED A BOOK on the social impact of human genetics research (*Unnatural Selection: The Promise and the Power of Human Gene Research,* Bantam Books), the cover of your last issue caught my eye—and the coverage of human stem-cell research inside the magazine impressed me greatly.

I have been startled by the fact that the general press has worn blinders about the search for human stem cells, despite all the ballyhoo that has followed Dolly the sheep. Conflicts about discrimination based on genetic testing, difficult as they are, are far easier to resolve than turmoil about our relationship with those entities at the earliest stages of human existence. Regalado is absolutely correct when he states that our inability to come to terms with this field of science—and therefore our impotence in overseeing it—is one of the most important social issues of our time. Congratulations to *Technology Review* for having the insight and the temerity to point this out (and the competence to report the issue so thoroughly).

LOIS WINGERSON
Editor in Chief
www.hmsbeagle.com

WHILE ANTONIO REGALADO'S excellent article on human embryonic stem cell research will help readers understand the concept and potential clinical benefits from this important area of science, it is misleading on one important point. The sidebar "Embryos and Ethics" states that researchers' federal funding "could be at stake" if they fertilize embryos "specifically for the purpose of research."

It is true that in 1997 Congress banned federal funding for the creation of a human embryo for research purposes or for research in which embryos would be discarded, but this ban applies only to federally funded research. The law forbids the National Institutes of Health and other federal science agencies from funding human embryo research or from conducting it in their laboratories. It does not, however, ban *privately* funded embryo research.

Of course, to carry on such studies with private funding requires moral courage of a high order—which researchers working to isolate, identify and grow embryonic stem cell tissues are showing.

JOHN C. FLETCHER
Professor of Biomedical Ethics (emeritus)
University of Virginia

We welcome letters to the editor.

Write: *Technology Review*, Building W59, Cambridge, MA 02139. Fax: (617)258-8778. E-mail: <technology-review-letters@mit.edu>. Please include your address, telephone number, and e-mail address. Letters may be edited for clarity and length.

Is It Science?

YOUR ARTICLE ON IBM'S DEVELOPMENT OF magnetic storage ("The Big, Bad Bit Stuffers of IBM," by Claire Tristram, *TR* July/August 1998) twice makes the error of calling "engineering" by the name "science." At the bottom of the first page, Tristram writes that the IBM group "squeezed more than 11 billion bits onto a single square inch of material....By any measure, this was a great scientific accomplishment." No: It was a great *engineering* achievement. Later, the author quotes Currie Munce, director of storage systems and technology at the IBM Almaden Research Center, as saying, "We're trying to move things mechanically over millimeter distance in milliseconds and get them to settle within microns on track. It's great science." If he actually said this, then shame on him. He certainly knows that he was talking about a tough engineering challenge, not a matter of basic science.

JOHN GOODMAN
Garden Grove, CA

An Ill Wind

IN "TIME FOR FRESH AIR" (TR JULY/August 1998), Michael Dertouzos advocates increased technological priority for new kinds of user interfaces as a means to increase productivity. But if the computer has not attained its productivity potential, it is not because there has been insufficient technological dedication to the user interface, but rather because there has been *too much* emphasis on that aspect. Driven by market objectives, manufacturers seek user-friendly designs that will make the computer salable in the mass market. There is too much emphasis on accessing information and entertainment, and not enough on software to assist us in

creating and understanding information.

Where is the symbolic-numeric software that allows one to "interactively experiment" with scientific ideas, while at the same time being easy to use and powerful enough to deal with nontrivial problems? And while the politicians call for a computer on every school child's desk, where is the software to allow these computers to be real learning tools, not just rote exercise machines or extensions of the school library?

RICHARD L. PESKIN
Professor Emeritus, Rutgers University
Londonderry, VT

Dertouzos responds:
Professor Peskin is right on the untapped productivity potential of computers. However he is wrong, along with many software vendors, in separating software into a cosmetic user interface and a more substantive inner part—imagine if you looked at your car that way. What we need and what I'm calling for is fresh air in making the entire system easier to use by people for their own productive purposes.

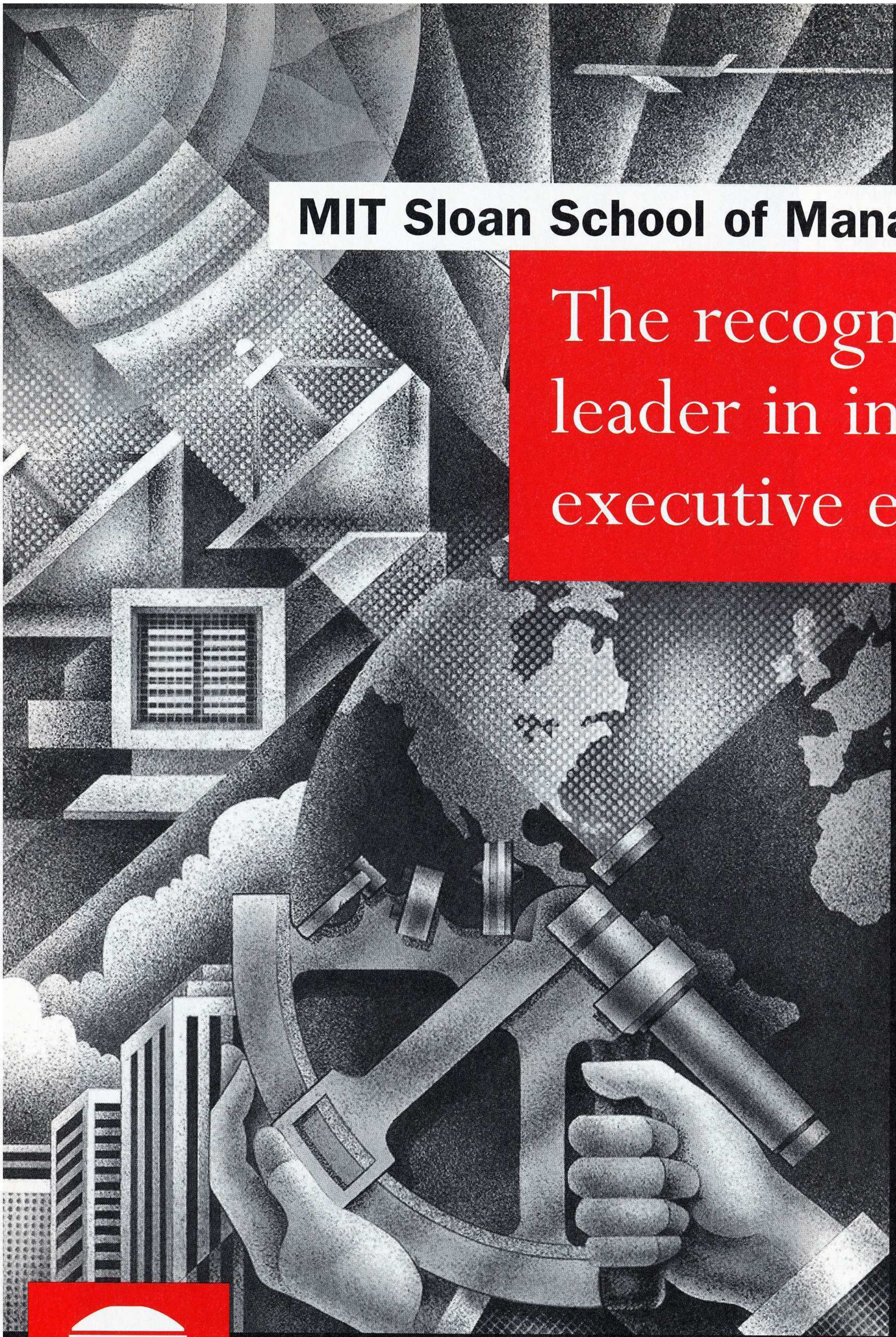
Very Bad Guys

WADE ROUSH'S REVIEW OF *HIROSHIMA'S Shadow* ("The Long Shadow of the Bomb," *TR* July/August 1998) suggests that we Americans engaged in "moral compromises" when we let fall over the Japanese cities of Hiroshima and Nagasaki the only nuclear weapons that have ever been used in warfare.

But this argument misses the point. We did not start the war. The designers of the Smithsonian Institution's 1995 exhibit on the bombing deserved the criticism they received because their display neglected to remind the intended audience of the rape of Nanking, the sack of Manila, the Bataan death march and the murder of hundreds of thousands of Chinese in reprisals for Jimmy Doolittle's raid on Tokyo.

The people who ran Japan in the 1930s and 1940s were very bad guys. It's about time we stopped beating our breasts and murmuring a pious *mea culpa* for ending one of the most grisly periods of unprovoked barbarism in the history of mankind.

FREDERICK H. HOWELL
Bethesda, MD



JONATHAN DAY/UNIVERSITY OF FLORIDA

Lured bugs never bite again

Fly Fencing

People living in coastal areas sometimes feel that they are little more than meals for a blood-sucking pest: the sand fly. Now, University of Florida entomologist Jonathan Day has come up with a way to reduce sand fly populations by taking advantage of the very mechanism that enables these pests to find their prey. Sand flies are attracted to the CO_2 exhaled by living organisms. Day built a fence that attracts the flies by emitting a carbon dioxide mixture through PVC pipes, then traps them in fabric panels covered with mineral oil. The fence could be used in sporting complexes, playgrounds or backyards. Over a three-year period, about 180 meters of fencing along a mangrove-lined canal in Vero Beach, Fla., cut the sand fly count by a factor of three, says Day. Air Liquide, a gas supplier whose U.S. R&D operations are in Chicago, has patented the trap.

Filling the Fiber

Imagine an interstate highway that was permanently hampered by an undriveable ridge running along one or two high-speed lanes. Traffic would suffer, to say the least. That's roughly the situation facing designers of the world's fiber-optic information thoroughfares. The manufacturing process that leads to the production of optical fiber has inevitably introduced hydroxyl ions into the ultrapure glass; these absorb light strongly at certain infrared wavelengths, rendering the fibers unacceptably opaque across a big chunk of the spectrum centered at about 1,400 nanometers. Lucent Technologies says it has solved the problem, purging most of the nasty hydroxyl from its fiber-making process. The resulting "AllWave" fiber, due on the market late this year, can boost capacity by carrying optical signals at some 150 individual wavelengths that the older fibers rendered unusable, says Lucent.

Let (Some) Sun Shine In

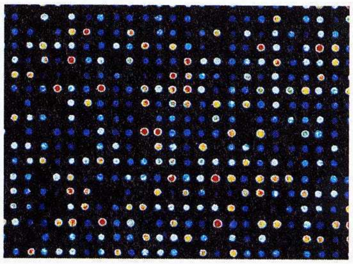
Imagine darkening a window with the turn of a knob. Such technology exists, but has been costly to install. The National Renewable Energy Laboratory (NREL) in Golden, Colo., is trying to erase this barrier by combining two technologies: electrochromic materials that darken in response to electrical input, and photovoltaic (PV) devices that produce electric current from light. A transparent PV coating on the window provides the juice to activate the window's change from clear to nearly opaque, eliminating the expense of wiring the windows into the building's power. The PV coating would double as a light sensor, so windows could darken as the sun shone brighter. The PV and electrochromic films could both be deposited on a polymer sheet that is then glued to an existing windowpane, says NREL's David Benson.

NREL

Switch on the shades

Fingerprint of the Perfect Drug

A perfect prescription would fix what ails you, and leave the rest of you well enough alone. That's the ideal. The reality: Side effects bedevil almost all available drugs, and keep many others from ever reaching the market. A new approach for monitoring drugs' consequences in yeast cells could help sort the silver bullets from bombs more efficiently. Acacia Biosciences—a startup in Richmond, Calif.—is systematically "knocking out," or disabling, each yeast gene and studying what effect the loss of that specific gene has on the cell. The readout serves as a "molecular fingerprint of what the perfect drug would do," says Acacia CEO Bruce Cohen, since such a therapeutic agent would block the function of one—and only one—gene.



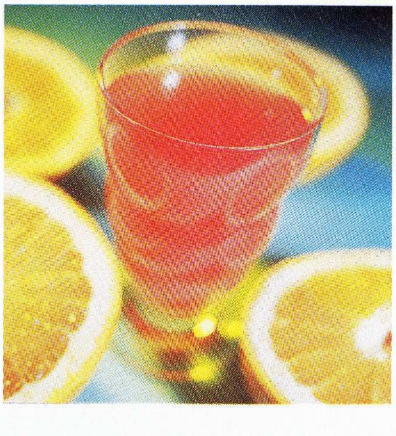
ACACIA BIOSCIENCES

Better medicine through yeast

Acacia is working with Eli Lilly to study test compounds in this "genome reporter matrix." Researchers introduce candidate chemicals into thousands of yeast colonies, and record the compounds' influence on each gene. The drug that gets closest to the "knock-out" fingerprint might be put on the inside track toward human testing.

Preserving Sweetness

Pasteurizing grapefruit juice often leaves it tasting bitter. Food scientists at Cornell University, however, have developed an "active" container to battle this consumer turnoff. The bitterness in grapefruit juice is caused by culprits that include the acid naringin. By coating the inside of the carton with a cellulose-acetate film harboring an enzyme that breaks down the acid, the food scientists have made the juice taste sweeter. The Cornell group, led by Joseph Hotchkiss, says such cartons show the feasibility of "active packaging" that doesn't just passively protect its contents but actually improves the quality of the food it holds.



VITO ALUIA

No-Pain Blood Tests

If you're one of the 8 million Americans who donate blood each year, you know that before you can give from the arm, you're going to get stuck in the earlobe or fingertip. This predonation anemia test boosts the nurse's risk of blood exposure and adds to the bill for biohazardous-waste disposal. Philadelphia-based Cytometrics plans to put an end to those problems with the Hemoscan, a device that tests blood—without drawing any.

Slip a thermometer-like probe under your tongue for a moment, and the Hemoscan tells instantly whether you're good to give. The probe houses a light source and a miniature camera that captures a video image of blood flowing through tiny vessels; a computer analyzes the spectrum of the reflected light and calculates the levels of red cells and hemoglobin. Cytometrics, working in partnership with the American Red Cross, hopes to have the device on the market next year.

Crossing Guard

VITO ALUIA

A school bus approaches a railroad crossing and the driver can't see the train coming down the track—for parents, that's the stuff of nightmares. But the Minnesota Department of Transportation (MnDOT) has just finished a six-month trial of a "smart" system designed to keep kids safe at the crossing. MnDOT engineers installed communication antennas in railroad crossing signs and in the front license plate of each bus in one school district. As a bus approaches a crossing, the plate picks up a warning signal sent out by the sign. A dashboard display connected to the smart plate flashes and beeps to alert the driver that a crossing is coming up, and whether a train is near. Project manager Ben Osemenam called preliminary results from the experiment "very positive," and says the MnDOT is gearing up to test the system at crossings that don't have lights.

PATIENT COMFORT

Probing a poker-faced patient

Put Me Under!

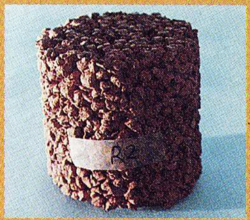
"Scalpel!" calls the surgeon. You'd like to yell, too, since you are a patient who has just come to in the middle of an operation—the knockout drops that the anesthesiologist gave you have worn off. But you can't move a muscle, because the paralyzing drug you were also given is still working just fine.

Nightmare scenarios like this one, dubbed "awareness" episodes, affect one in 500 surgery patients (or about 40,000 each year in the U.S.). Existing methods to detect awakening, which include measuring heart activity and brain waves, are far from perfect. To improve on them, experimental psychologist Henry Bennett invented the FACE monitor. This device detects micro-expressions—say, barely perceptible grimaces of pain—with electrodes that measure voltages in four groups of facial muscles. Bennett says the software he's written can identify the emotion behind the signals, which originate deep in the brain. The FACE monitor is being developed by his Chatham, N.J., company, Patient Comfort.

Steel-Belted Silence

Automobiles leave mountains of used tires: Two billion tires have accumulated in piles across the United States alone. Researchers at the Instituto de Acústica in Madrid, Spain, are using this waste to ameliorate another environmental impact of the automobile by packing crumbs of rubber from discarded tires into highway sound barriers.

Rubber turns out to have a broad sound absorption spectrum well-suited to traffic noise, and the tire crumbs stand up better to rain and dust than the glass and rock wool used in traditional sound barriers. Reverberation room tests have shown that the smaller the rubber crumbs are, the better they absorb sound. In June, the Madrid researchers tested a full-scale prototype barrier made with the recycled rubber.



INSTITUTO DE ACÚSTICA

Tire crumbs muffle car noise

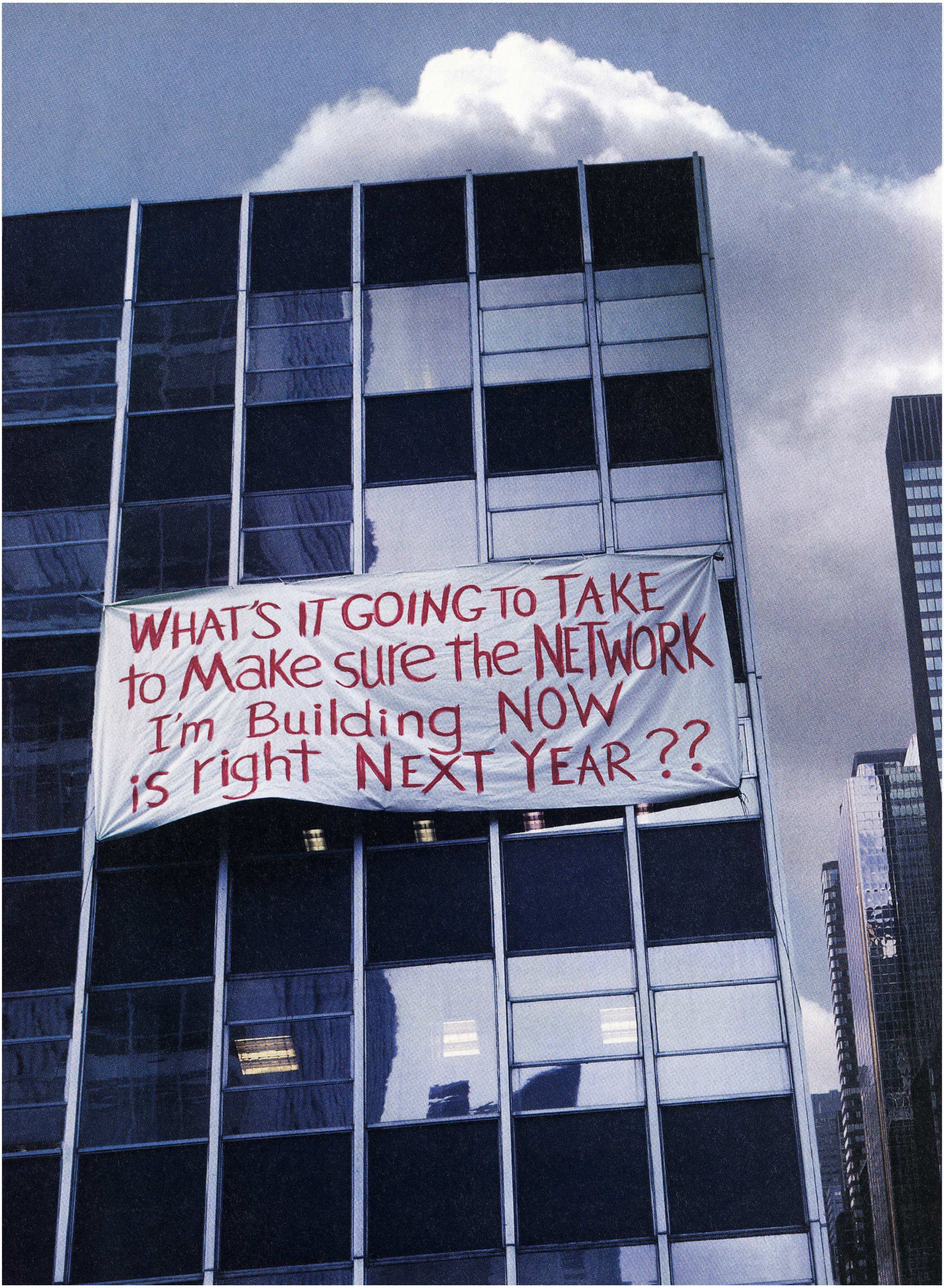
Heavy Metal—Quickly

"Rapid prototyping" methods of making models of objects from computer files can dramatically cut the time from the drawing board to market. Most such procedures now in use create plastic representations of metal items. But for many manufacturers, that's not nearly as valuable as being able to rapidly create the piece in metal. Now, researchers at Sandia National Laboratories say they've come up with a way to use lasers to fabricate metal parts directly from a computer model, in a matter of hours.

In Sandia's process, a beam is focused to a small spot on the surface of a metal substrate, forming a molten pool. Metal powder injected into the pool solidifies into a bead that protrudes from the surface. Repeating this many times under computer direction builds up the prototype. Ten companies, including 3M, Eastman Kodak and Lockheed Martin, are supporting Sandia's effort to the tune of $3 million over two years.

SANDIA NATIONAL LABORATORIES

Laser-shaped stainless steel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Wire All Schools? Not So Fast...

A FEW MONTHS AGO, ISRAELI PRIME MINISTER Binyamin Netanyahu explained to a group of politicians and computer professionals how he wanted to provide a quarter-million of his country's toddlers with interconnected computers. Netanyahu was concerned because he had had trouble funding the project. I turned the tables and asked him why he wanted to do so in the first place. He was stunned, since it should have been obvious to anyone—especially to an MIT computer technologist—that computers are good for learning.

Throughout the world, droves of politicians, led by those in the United States, are repeating this fashionable mantra as they proclaim that millions of children in thousands of schools will soon be interconnected. You can feel their rush: "Isn't it so responsible and oh-so-modern to put an emerging technology to work toward the noblest of social goals: the education of our children?" Not quite.

After 35 years of experimenting with computers in various aspects of learning, the jury is still out with respect to the central question: "Are computers truly effective in learning?" That's what most educators who experiment with computers disclose, as I have steadily heard them say, for example in the Technology-in-Education Conference held in May in New York.

Certainly the promises of computers for learning are impressive. Simulation, for example, is already a proven winner. Besides pilots, tank commanders in the Gulf War who spent a great deal of training time on tank simulators attest to the success of this approach. Simulation can be nicely extended to other kinetic and quantitative tasks such as learning how to drive, ski, swim and sail, and, someday, even perform surgical operations. But we may be unable to build simulators for more qualitative situations, such as teaching a manager to handle a disgruntled employee, through a video simulation of the encounter.

Stand-alone computers can also help people write, compose music, generate designs and create new artifacts by bringing to our fingertips approaches, techniques, forms and patterns that have been successful in similar past endeavors. Machines are particularly effective as literacy tutors for adults who don't have to feel embarrassed as they read aloud from a primer to a machine that listens to them and corrects their mistakes. Computers can also be used as "tutors," for example by students who learn French by interacting in French with an adventure game in which the goal is to rent an apartment in Paris. The bolder notion of computer apprenticeship, where a Frank Lloyd Wright simulator analyzes your architectural drawings as the great master might have done, is still in the imagination stage.

Moving to the world of interconnected computers, we can see them being used for straightforward tasks such as sharing teacher information, posting homework on the Web (thereby eliminating children's ancient excuse that they forgot their homework assignment) and getting useful information from trusted sources, as well as for many educational activities that involve e-mail and access to distant Web pages. Distance learning is another emerging capability of interconnected computers, particularly useful in matching locales where certain teaching specialties are unavailable with places that have the right people and the right knowledge.

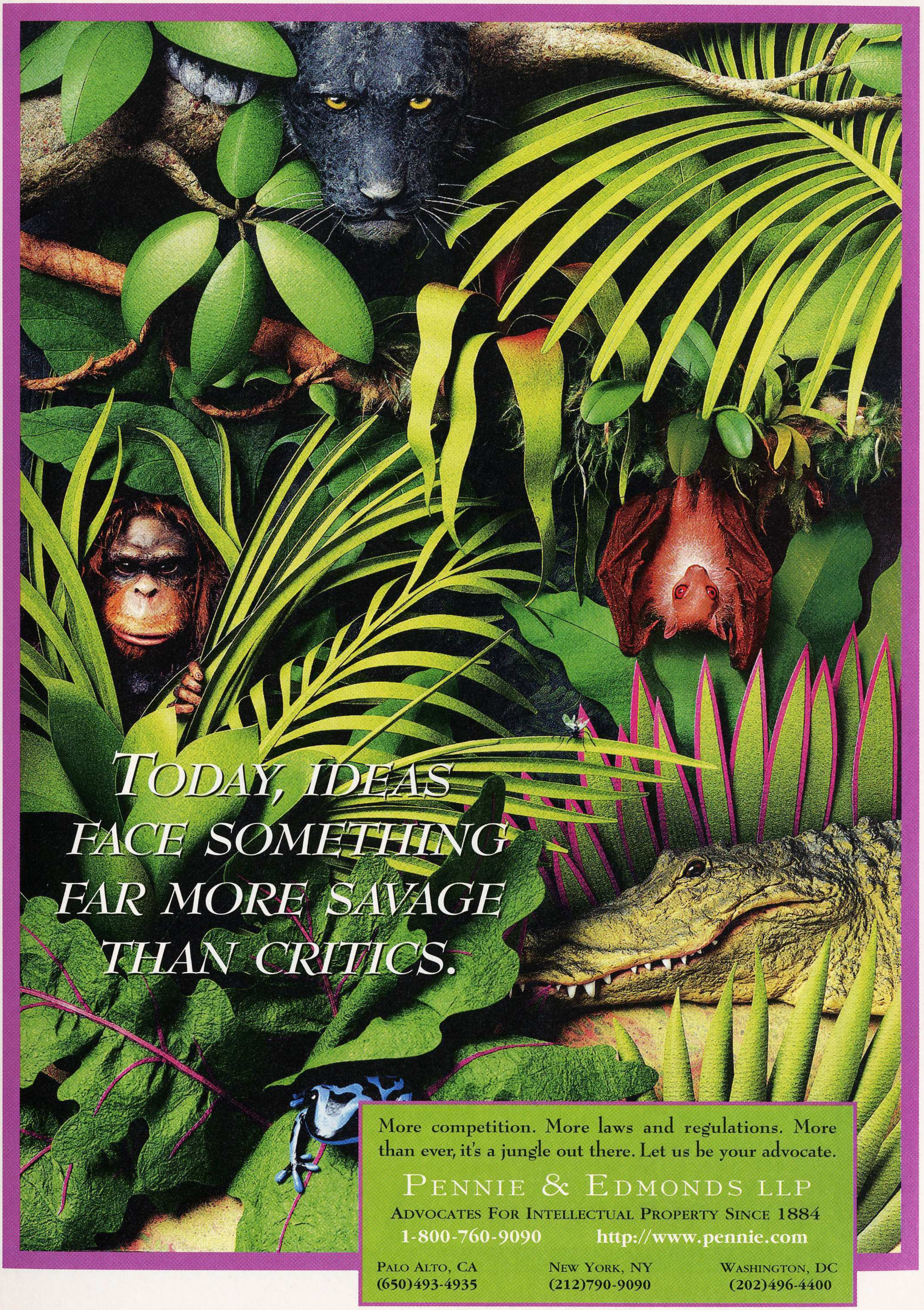
If we can agree on some shared conventions, we might even construct my dream—a distributed virtual world heritage museum where each nation posts its writings, sculpture, music and other cultural offerings on the Web and the rest of us, flying a virtual histori-copter, soar easily in space and time, from Plato to Confucius to the Renaissance.

Learning may critically depend on what humans, not computers, do best: lighting a fire in a student's heart.

The achievements and promises of computers for learning go to the heart of the information revolution: Unlike the agrarian and industrial revolutions that helped learners indirectly by feeding them, transporting them to school and providing them with electricity, the information revolution helps much more directly because it deals with the principal currency of knowledge—information.

In light of all this potential, how can anyone argue that the jury is still out? Well, take U.S. high school students. They consistently rank from 12th to 18th, internationally, in physics and math, whereas Asian students rank first. Yet U.S. students have far greater access to computers than their Asian counterparts. Might there be some ancient, obvious and major thing about learning that we could learn...if we only lifted our heads long enough from our screens to look at our better educated neighbors? Another, possibly related, reason for the jury to be out is that learning may critically depend on what humans, rather than computers, do best: Lighting a fire in the student's heart, role modeling and nurturing may contribute more to learning than the neatest hyper-linked courseware.

So what are we to do, confronted as we are by high promises on one hand and a jury that's still out on the other? I suggest the same answer I gave to Prime Minister Netanyahu: Experiment creatively and massively (in the thousands), but refrain from deploying massively (in the millions)...at least until the jury has something to say. This won't make politicians shine as bright, but our children may ultimately shine much brighter. ◊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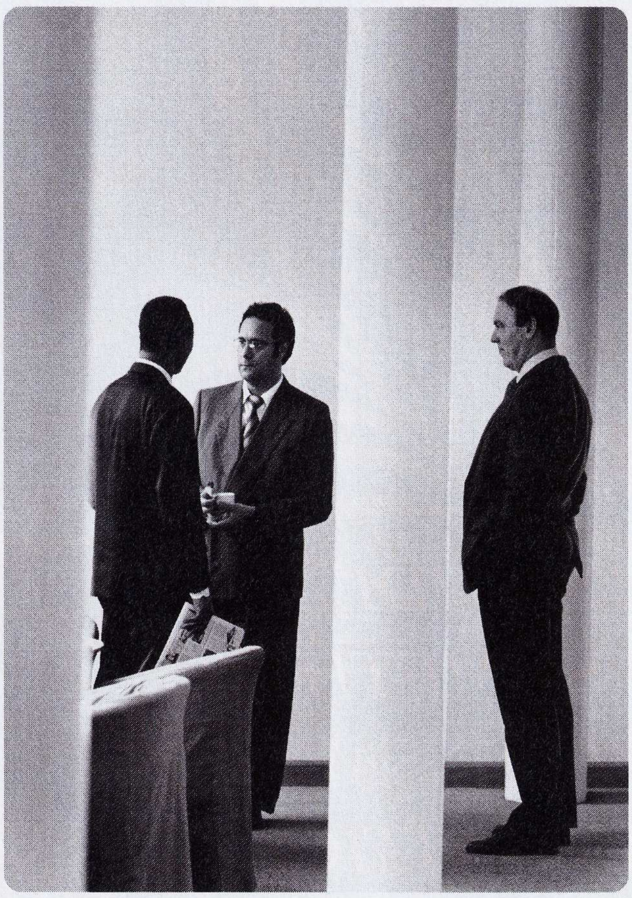
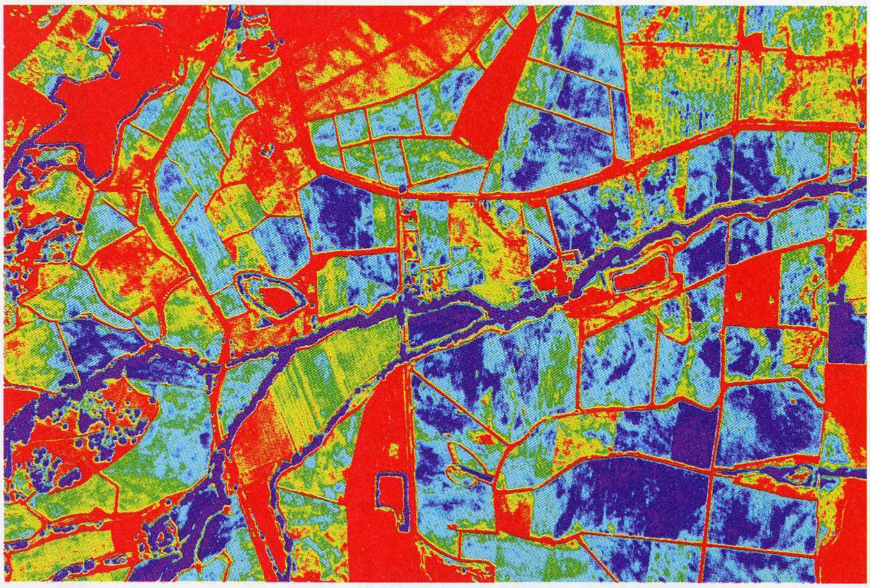


AGRICULTURE

Winegrowers Harvest a Space-Age Technology

Remote sensing is being used to find the perfect grapes



NASA AMES RESEARCH CENTER

Aerial wine tasting: Images of Mondavi vineyards help spot fields ready for harvest.

WINEMAKING ISN'T EXACTLY HIGH-tech. You take some grapes, add a little sugar and yeast—then let nature take its course. But now National Aeronautics and Space Administration (NASA) researchers are helping bring space-age technology to the ancient art of making wine in a partnership with Robert Mondavi Winery in California's Napa Valley. The scientists at NASA's Ames Research Center in Mountain View, Calif., are collaborating with Mondavi to explore the use of digital remote sensing data in vineyard operations. The remote sensing data help winegrowers harvest their grapes with more precision—yielding higher quality wine.

There are many different kinds of remote sensing instruments, some of which pick up information invisible to the naked eye. The class of remote sensing instruments known as "multi-spectral imagers" measure radiation in the visible and near-infrared parts of the electromagnetic spectrum. For the Mondavi project, NASA acquired multi-spectral imagery from a digital camera flown on an airplane at 14,000 feet over Napa Valley. The data were then processed to create a special "vegetation index" emphasizing information on the amount of chlorophyll in the plants, which can be used to make estimates of plant health and maturity. "The vegetation index is calculated using relatively narrow spectral bands centered in regions that are perfect for looking at vegetation," says Lee Johnson, senior remote sensing scientist at NASA Ames.

The Mondavi growers study the vegetation index maps to find out which parts of the field have similar plant density or vigor. These discrete areas can be sampled on the ground for maturity and harvested separately. Traditionally, Mondavi harvested an entire vineyard block at once. But the conventional method results in some grapes being overripe when harvested, and others underripe. Subdivision of the vineyard based on remote sensing characterization allowed Mondavi to harvest segments of its fields at different times to coincide better with optimal ripeness.

The early results of this work are promising. Mondavi has produced wine from experimental fields of chardonnay and pinot noir grapes, and Daniel Bosch, Mondavi Vineyard technical manager, reports that there are clear improvements over traditional harvesting methods. "There were portions of the vineyard that were previously not used for our higher quality wine. But now the wine from some of those same blocks will be used in our reserve program. That's a big step for us," says Bosch.

"What we're doing is separating the wheat from the chaff," explains Bosch. "So although some of the wine from the remote sensing experiment was better, some of it was not. This forced us to look more closely at those weaker areas. And this is leading us to a much better understanding of what's going on in the vineyard."

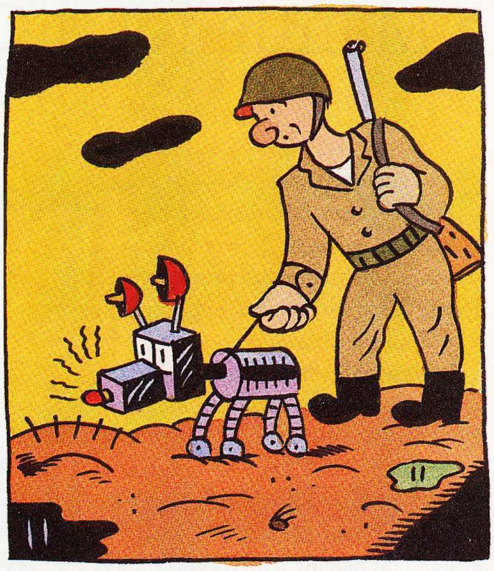
As a result of its work with NASA, Mondavi plans to incorporate the remote sensing technology into operations on a regular basis next year. And the operation may go to an even higher-tech level in the next harvest. The first satellite to yield data specifically for agricultural use was scheduled for launch later this year by a company called Space Imaging, based in Thornton, Colo. Assuming there are no glitches in the satellite's operation, Mondavi plans to buy processed images from Space Imaging for future growing seasons. In the end, of course, how widely these methods are adopted in the winemaking industry will be—like everything else in winemaking—a matter of taste.

—Joy A. Colucci

CHEMISTRY

Sniffing Polymers: A Soldier's Best Friend?

New sensor could mean safer land mine detection


MARC ROSENTHAL

AT THE BEGINNING OF SEPTEMBER, MIT chemist Timothy Swager and several of his students were set to travel to the United States Army's Fort Leonard Wood in Missouri to try their skill at detecting land mines. It's only a preliminary test and the mines were deactivated. But the scientists were armed with a portable device that incorporates a novel conducting polymer—and a clever molecular detection scheme—that could trigger a breakthrough in chemical sensing.

Land mines continue to be a menacing presence around the world, and methods for quickly and safely spotting them remain woefully inadequate. Indeed, dogs are still one of a soldier's most reliable friends in sniffing out the deadly devices. Metal detectors often turn up false alarms. More sophisticated and expensive analytical instruments tend to be bulky and can have trouble picking up the "smell" of land mines.

What the U.S. military "really wants is the equivalent of the tricorder they have in Star Trek," says Swager. Short of that, he says that the Defense Advanced Research Projects Agency, which is helping to fund his work, would like a very sensitive detector that is easy to use. "Something basically like a TV remote," says Swager.

And that's exactly what Swager is hoping to make, using conducting polymers to do the sensing. The MIT chemist has synthesized polymers that are, in essence, molecular wires with receptors strung along the polymer backbone. The polymers fluoresce, but when the right molecule, say, nitrogen-containing TNT (2,4,6-trinitrotoluene), binds with one of the sites, it reduces the fluorescence, indicating the compound's presence.

But here's the trick. A single molecule binding to one of many sites in a polymer might be expected to produce only a weak signal. In the conducting polymers, however, energy races through the macromolecules prior to fluorescence; a molecule that binds with even one of the sites deactivates this energy flow, greatly increasing the reduction in fluorescence and amplifying the signal.

Swager has made thin films of a fluorescent conducting polymer that are stable and capable of detecting a whiff of TNT at levels below one part per billion. Swager's ambitions, however, go far beyond TNT; the group is modifying the polymers with different types of sites capable of detecting other molecules, as well as increasing the sensitivity by switching to an electrical signal, rather than fluorescence. Targeted applications include portable, real-time sensors for biological and medical applications.

That will take time. For now, Swager is intent on mimicking a canine's talents. "A dog smelling a buried land mine twenty yards away will trot and stop on a dime 2 feet away from it," points out Swager. A man-made device with that kind of sensitivity is still a ways off, he acknowledges. "It's a big challenge in any vapor detection to do it as well as a dog can."

—David Rotman

BIOMEDICINE

Star War on Cancer?

In the latest escalation of the war on cancer, the National Cancer Institute (NCI) is arming itself with some high-risk tactics borrowed from the Department of Defense.

In June, NCI launched the Unconventional Innovation Program (UIP), a five-year, $48 million bid to come up with novel technologies that could someday tip the balance in man's battle with malignancy. The aim, says Carol Dahl, director of NCI's office of technology and industrial relations, is no less than "quantum improvements and entirely novel approaches" in fighting cancer.

The program is modeled on the Defense Advanced Research Projects Agency (DARPA), home of some of the most successful federal funding of daring technological endeavors. (DARPA was, for instance, the initial sponsor of the Internet.) "The notion is that the bizarre and the weird sometimes have the greatest impact," says Franklin Prendergast, director of cancer research at the Mayo Clinic and a member of NCI's Board of Scientific Advisors. Most of NCI's $2.5 billion per year in research funding is doled out through a peer-review process that Prendergast says "overlooks technologies that challenge dogma."

NCI is seeking outside-the-box innovators who can implement such science-fiction concepts as injectable tumor-killing nanorobots or smart polymers that both detect diseases and deliver drugs. The cancer institute will award the first grants in 1999, favoring multidisciplinary projects that cut across fields such as microfabrication, photonics and chemical engineering.

—Antonio Regalado

INFOTECH

Trade You (Online) a Mantle for a Clemens

Digital baseball cards *hit* the World Wide Web

FOR YEARS, BASEBALL CARDS HAVE helped fans express their devotion to their sports heroes. Now, an inventor with a love of baseball promises to update the age-old pastime in a highly computerized fashion.

It all began when Marty Marion, an advertising executive named after a St. Louis Cardinals shortstop of the 1940s and 50s, was on a flight from Los Angeles to New York. Sitting next to him was a 7-year-old kid who spent the entire flight playing with his space alien trading card. Marion watched the boy repeatedly animate and flip the card in the air. Eventually, he realized that for the kid, the card was a true-to-life friend. "That's when I thought it would be a great idea if I could make trading cards come to life electronically. I quickly started to work on the idea of taking video and audio and embedding it on a trading card on a computer," Marion says.

With $300,000 of his own money, Marion started a company called CyberAction Inc. (www.cyberaction.com), based in New York's Silicon Alley. Three years later, visitors to the Web site can purchase baseball, soccer and celebrity cards that exist only in digital format.

Marty Marion 1948 baseball card (left). CyberAction's digital version of Ken Griffey, Jr.

A pack of four digital baseball cards costs $3.95. The cards feature audio and video clips of players—for example, a 1920s film of Babe Ruth, or a 1990s video of Roger Clemens. By flipping the card electronically, you can play sports trivia games, see a player's entire lifetime statistics, hear the crowd cheer or boo, and drag and drop images to create an electronic poster of your favorite player.

Collectors can order and download cards online. Next year, the site expects to initiate online trading. Serious collectors will appreciate the fact that the first-ever digital baseball cards have an official license from Major League Baseball and are distributed in limited editions.

The technology behind all the fun and games is a system developed by CyberAction. Collectors of the digital baseball cards download software that allows the encrypted and video-enhanced cards to be fully activated, organized, viewed and ultimately traded.

The company has also signed licenses with Major League Soccer for digital soccer cards and with Universal Studios for *Xena: Warrior Princess* and *Hercules* cards. The developers have high hopes to expand the menu of CyberAction. Targets for agreements include the National Football League, National Basketball Association, and TV shows Baywatch and Star Trek.

While some may applaud the introduction of a new and improved baseball card, for others perhaps the most interesting part of Marty Marion's invention is his claim to have created a business model that expects to turn a profit on a 100 percent digital product that has no traditional manufacturing costs, no real-world retail outlet and virtually no incremental production costs. "Once we have sold enough cards to pay for the initial development and creation cost for the first set, duplicating the electronic file to fulfill customer orders is simple and done at no cost other than the royalties we pay the licensor," Marion claims. If he succeeds, it will be a triple play!

—Katherine Cavanaugh

MATERIALS RESEARCH

The Beach Yields a Bright Idea

T. J. KELLY

Prospects for silicon-based phosphors are bright.

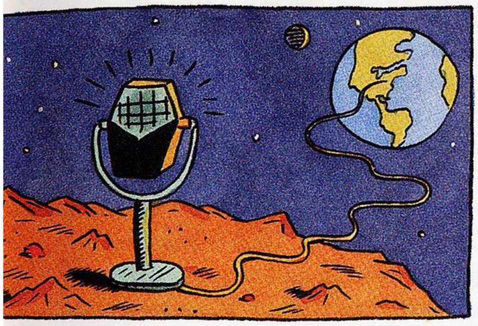
Fluorescent lighting is the bane of many office workers' existence. But that isn't the only drawback of this form of illumination. The "phosphors" in a fluorescent light (the compounds that actually produce the visible radiation) typically contain such toxic metals as cadmium, silver, europium and lead. A California chemist has synthesized a surprising new compound made of the same elements found in beach sand (including a trace of driftwood) that might provide the basis for more environmentally benign phosphors. And now a Tokyo-based company, C.I. Kasei, sees a bright commercial future for this intriguing new luminescent material.

Materials chemist Michael Sailor of the University of California, San Diego (UCSD), discovered last year that when he reacted carbon with a combination of silicon and oxygen (the elements in sand), the result was luminescent. "The carbon is behaving like metals do in the conventional phosphors, and that's the surprising part," says Sailor.

In recent work, Sailor has turned up the light-emitting properties of his compounds by adding a sprinkle of aluminum. Phosphors with the added aluminum provide illumination comparable to conventional fluorescents, Sailor told *TR*. He thinks the new compound also could be used in computer screen displays and wristwatches.

Some of these applications might be put to the test soon. C.I. Kasei has signed a deal with UCSD that allows the company to further develop the material.

—David Graham



MARC ROSENTHAL

SPACE SCIENCE

Sound Bites From Mars

WE ALL KNOW WHAT MARS LOOKS like close up: The burnt-orange, rubbled landscape is familiar, thanks to last year's Pathfinder spacecraft photographs. But who knows what a day on Mars sounds like? Well, soon it will be possible to hear the sounds of Mars.

The National Aeronautics and Space Administration (NASA), working with scientists at the University of California, Berkeley, is placing a microphone aboard the Surveyor '98 Lander spacecraft, scheduled to launch in January for Mars and due to arrive the following fall. Once on Mars, the microphone, which is the size of a matchbox, is expected to record wind, sandstorms and the crackle of electrical discharges in the atmosphere.

Miniaturization made the microphone small enough and sufficiently power-stingy to meet NASA's requirements. The entire device is 5 centimeters square and 1 centimeter thick, and weighs 56 grams. The project was completed for less than $100,000, paid for by the Planetary Society, a private organization advocating space exploration.

With telemetry time tight, researchers expect to relay a 10-second sound bite every third day during the month-long mission. And in a collection that could turn out to be a sort of "Mars' Greatest Hits" the sounds will be posted on the Planetary Society's Internet site: http://planetary.org.

If the microphone records something particularly compelling, more elaborate devices might be sent. And someday the "greatest hits" may become a full symphony.

—David Graham

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The Intelligent Workplace's sunny interior.

CARNEGIE MELLON UNIVERSITY/CBPD

ARCHITECTURE

Improving the IQ of Offices

A "smart" office tries to prove its worth

THE "INTELLIGENT WORKPLACE" AT CARNEGIE MELLON University has, without question, the best view on campus. Built atop an existing building, it commands an almost 360-degree panorama and, equipped with state-of-the-art office technology, is an unusually pleasant place to work. But it's also a place with a tough job: to prove that an initial investment in a "smart" facility not only benefits workers but also saves money in the long run.

The showcase office is a collaborative effort of Carnegie Mellon's Center for Building Performance and Diagnostics (CBPD) and the Advanced Building Systems Integration Consortium, made up of government agencies and manufacturers of building and office products and systems. The project tests new technologies and hopes to demonstrate that these systems together as an integrated whole can result in significant savings over a building's lifetime.

But they've got a tough sell. "People are willing to pay money for a better car environment, where they spend maybe one or two hours a day, but collectively they are less willing to spend money to improve the work environment, where we spend 10 hours a day," says CBPD's director, Volker Hartkopf. "We question that."

The Carnegie Mellon project maximizes use of natural light and ventilation in the workplace. When the outside temperature and humidity fall within a certain range, a computer tells building occupants to open their windows. "Today it's humid in Pittsburgh, but not hot, just warm, and opened windows are all we need (for ventilation)," Hartkopf said one day this summer.

The computer also controls light redirection louvers outside the windows. When the windows are closed, water flowing through the mullions separating the window panes provides heating and cooling. Ventilation comes from personal modules at each desk; the units tap into an air supply under the floor and allow each worker to control temperature and flow rate—even to generate masking noise.

To accommodate the personnel and organizational changes that are increasingly common in today's workplaces, layouts, walls, electrical wiring and phone lines are all easily reconfigured. The wiring system, for instance, is a network of consolidation boxes under removable floor panels; it provides access to every point in the space within 30 centimeters, and does so for less money than a conventional wiring system. "If you're a company relocating your headquarters, you could even take the wiring along with you," points out research assistant Sila Berkol.

Berkol points to studies that show that this kind of up-front investment in a work environment pays for itself over the long haul. Lower energy costs and infrastructural versatility are only part of the picture: the subsequent reductions in medical insurance costs and absenteeism and increases in productivity and employee retention alone can be enough. Not to mention the many other less easily measured benefits that result from a workforce that likes being at work. **—Deborah Kreuze**

MEDICAL DEVICES

Heart Hackers

To get their scalpels onto an ailing heart, surgeons usually have to crack open a patient's rib cage—not a pretty sight, nor a procedure helpful to the healing process. That standard method may change soon: Using experimental robotic surgical instruments, physicians in France and Germany have performed a series of ground-breaking heart operations through dime-sized incisions, without any rib cracking at all. The advances culminated in late June when Alain Carpentier and Didier Loulmet of Broussais Hospital in Paris used the new techniques to perform a coronary artery bypass graft.

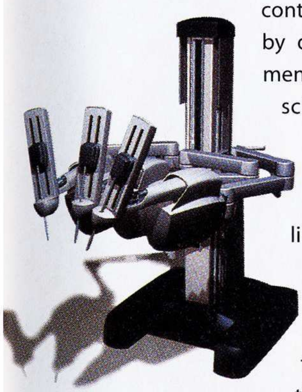
Minimally invasive surgery—which leaves patients with tiny scars and little post-oper-

The remote-control surgical suite.

INTUITIVE SURGICAL

ative pain—is already commonplace for procedures such as removing gallbladders. But more complex operations, such as heart surgery, have resisted minimally invasive methods, which generally require physicians to operate using awkward chopstick-like instruments. The French team of physicians was able to push the envelope thanks to a new system that gives joystick-wielding surgeons precise control over dexterous surgical instruments.

To use the system, originally developed at SRI International for battlefield telesurgery and now being commercialized by Intuitive Surgical of Mountain View, Calif., the surgeon sits at a console and peers into a close-up 3-D image of the patient's heart. The image is captured by a scope inserted between the patient's ribs through one of three small incisions. The remaining openings are for remote-controlled arms tipped by detachable instruments (choices include scissors, a suturing device and a grip) that swivel on an advanced wrist-like joint.



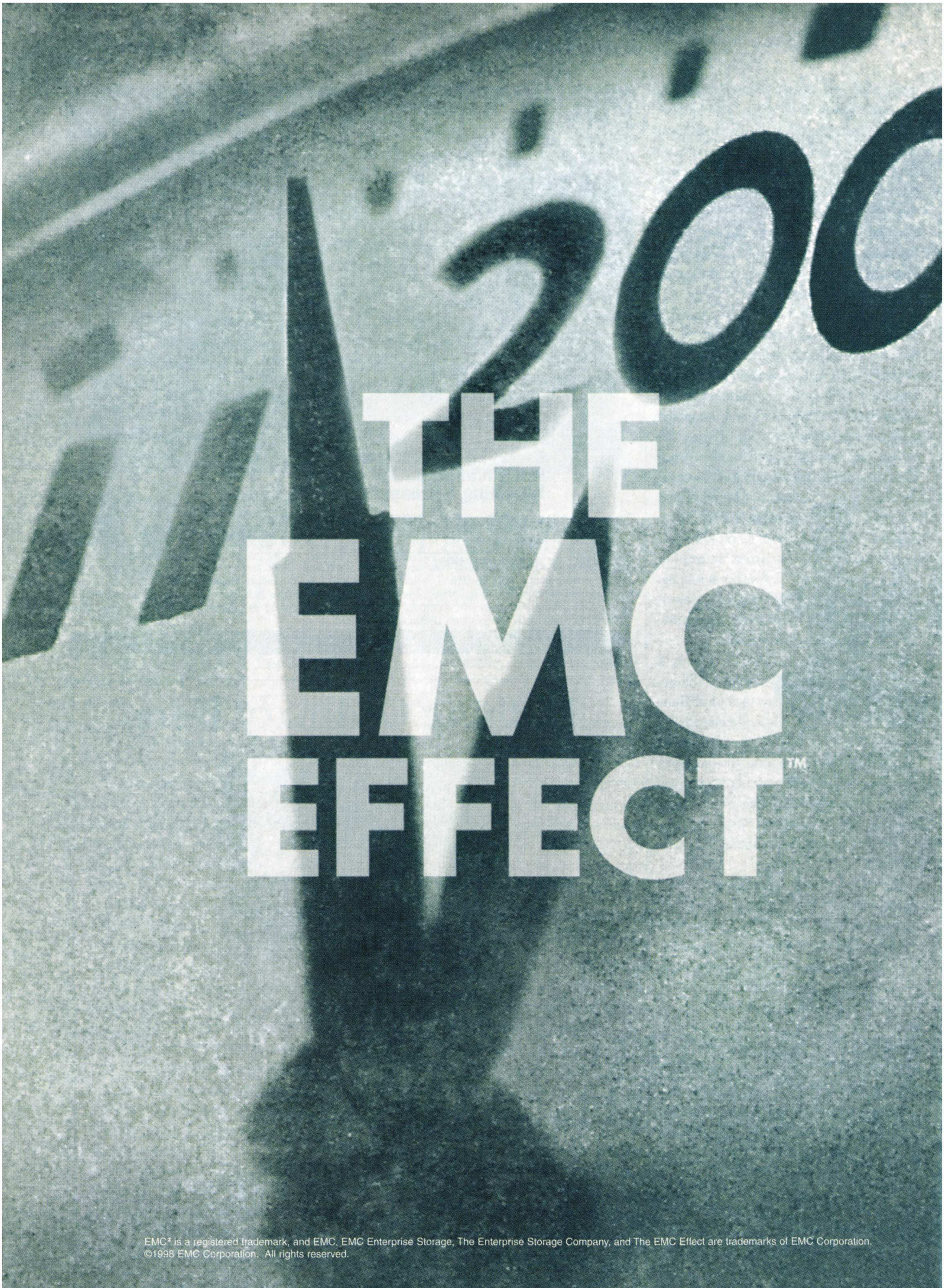
Intuitive Surgical's robotic arm.

Intuitive's Thierry Thaure, vice president for marketing, claims that surgeons find that the system's robotic hands are even more precise than their own. They're also steadier: The computer filters out unintended movements by the operator, such as shaking.

Not all heart surgeons are fans of "robosurgery," however. Although current methods can mean a painful recovery for a patient and a large scar, they are tried-and-true. What's more, in minimally invasive heart surgery, physicians must divert blood from the heart with a tricky system of catheters that can damage vessels. Thaure admits that getting doctors to try the novel setup may be challenging. They may, however, be persuaded to try it by their heart patients. The French doctors report that 24 hours after surgery their 69-year-old patient felt so good that he refused pain medication.

Intuitive Surgical plans to ask the Food and Drug Administration for permission to sell the minimally-invasive surgery system in the United States next year.

—Antonio Regalado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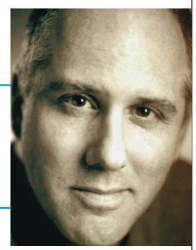
High-Tech Hubris

HOW AMBITIOUS CAN A GUY GET?

Not content with picking winners and losers in the volatile world of high-tech, John Doerr thinks he can re-engineer society too. His agenda is simple. First he'll fix the schools, then upgrade the skills of American workers and—who knows? —maybe finish off by bringing racial harmony to the land. And he won't even break a sweat because his ideas compute. Or so he beeps.

Only those out of radio contact with the digital world need an introduction to Doerr, a partner in the top-drawer venture capital firm of Kleiner Perkins, based in Menlo Park, Calif. Doerr is arguably the shrewdest, quickest and most celebrated venture capitalist alive. He's the Bill Gates of high-tech finance, or so say a stream of cheerleaders, from *The New Yorker* to *Wired* to *The San Jose Mercury News,* his local rag. Doerr doesn't just write checks, his fans insist; he actually concocts strategies and tactics, gazes into the future of technology, even hand-picks the executive team for his new ventures. While he has had his share of misses, his hits are tremendous. They include Sun Microsystems and Netscape.

Venture capitalist John Doerr is a smash hit in the world of technological innovation, but the early returns show that he has a lot to learn about how the game of politics is played.



To be sure, Doerr's high-tech achievements are impressive. But since when has that qualified someone as the public's savior? Maybe a general on the heels of a victorious war (Eisenhower, Colin Powell) deserves such status. Or even a family of aristocrats (the Roosevelts). But an electrical engineer with an MBA? That is new.

Doerr's ascension speaks volumes about the merger of celebrity and innovation in *fin de siècle* America. High-tech is hot; innovation is the new god. In the unbridled celebration, it is difficult indeed for a tech titan to banish thoughts of Napoleonic grandeur from the digital processor he calls his brain. The fawning attitude of the media, and of the political class, quickens this slide into megalomania. After decades of treating techies like members of the Belushi family, politicians have finally realized that these overgrown children are steering the engine of the American economy. Cozying up to a computer tycoon is now the equivalent of kissing a baby on Main Street.

The federal government has for decades zealously funded technological research and trumpeted to the nation the importance of innovation. But that's not the same as the president taking late-night phone calls from the CEO of Apple, or sneaking away on Air Force One for a clandestine briefing on the future of Windows. With *TIME* magazine declaring Bill Gates to be more influential than Bill Clinton, it is no wonder that lesser-known billionaires such as Oracle's Larry Ellison never go lonely at lunch.

The political odyssey of the technology industry's best and brightest began quietly back in 1992, when a group of high-profile computer executives publicly backed Bill Clinton for president. Four years later, many of these same folks supported Clinton again. Their endorsements proved crucial in both elections.

In the process of trucking with Democrats, the normally libertarian cyber set discovered the nation's capital—and old-fashioned politics. These days, Washington, D.C., is practically a second home to Bill Gates. Gates isn't alone in making the pilgrimage East. With less fanfare, Doerr and his pals are climbing all over the city too. And part of their agenda is to rail against Microsoft and the huge power Gates wields over the new economic sector that has developed as a result of the connections among four big industries: computers, software, television and publishing.

Doerr likes to think he has Gates on the run. And now that Vice President Al Gore is diligently wooing the digital rat pack, this may be true. Gore, inheritor of Clinton's high-tech connections, is creating a kitchen cabinet of advisers from computer and software industries. This year, Doerr emerged as the group's leader.

Re-engineering the nation's schools might seem a doable task if you think you can tame America's richest man. Yet while Doerr is sincere in wanting to make the classroom a breeding ground for high-output knowledge, he's a rookie when it comes to politics. And his inexperience shows. This spring Doerr took on a seemingly light political chore: He ran a vigorous drive to raise school taxes in the wealthy northern California hamlet where he lives. Despite putting his personal prestige on the line, his neighbors voted down the measure.

It was a stinging defeat and carried a lesson for any high-tech titan considering a role in politics. Doerr's own neighbors were unwilling, it seems, to put his ideas about education into practice, even in a wealthy district where Doerr's enthusiasm for self-reliance, limited government and the power of innovation is the common creed.

No doubt Colin Powell would have pushed through a ballot measure in his home town, even if it called for something far more controversial than improving public education. It just goes to show that the public is giving high-tech innovators more respect—but there's still nothing like winning one war to prove you deserve the power to start another one. ◊

Think growing naturally colored cotton is far-fetched? Think again. A new wave of genetically altered plants could turn fields into production lines not only for better foods but also for fabric, plastic and pharmaceuticals. **BY DAVID ROTMAN**

the next biotech harvest

PHOTOGRAPHS BY PATRICK HARBRON

At first glance, an aging industrial section of Cambridge, Mass., seems an odd place to look for the future of agriculture. The only plants are weeds along the railroad tracks and well-tended shrubs and trees dotting the entrances to the high-tech businesses that are rejuvenating the area. The agricultural heartland of the United States is a thousand miles away.

And you won't find any greenhouses or pots of experimental plants inside Cereon Genomics. It looks like any other molecular genetics lab. Technicians prepare bar-coded samples; nearby, rows of sophisticated instruments that were originally developed for sequencing human genes form a high-speed manufacturing line. The difference is that the raw materials for this gene factory are often snippets of plants, and the product is information on the plant's DNA—their genetic blueprints.

From his corner office, Roger Wiegand raises his eyebrows toward the automated equipment in back of him. Wiegand is Cereon's director of genomics technology—the science of identifying genes and their functions. There may not be any greenery around, but for a longtime molecular biologist, Wiegand says, running Cereon's lab is "like being a kid in a candy factory."

The excitement is based on the conviction that the gene information being harvested at Cereon—and at other plant genomics labs sprouting up around the world—will help seed a biotech transformation of agriculture. Monsanto, the St. Louis-based agricultural and pharmaceutical giant, late last year committed to spend over $200 million to create Cereon, a wholly owned subsidiary it formed in an alliance with gene hunter Millennium Pharmaceuticals. The deal is one of the boldest moves in Monsanto's makeover into a "life sciences" company. (In June, Monsanto announced plans to merge with American Home Products.) And it reflects the former chemical company's deep-pockets belief that it can leverage the growing knowledge of genes into big business—and in so doing change how farmers and consumers think about plants.

> The vision: rewire plants into cheap production units that can grow everything from modified foods to human vaccines to commodity chemicals.

Other companies share this vision. Several other chemical and drug giants, notably DuPont and Novartis (the Swiss company resulting from the 1996 merger of Ciba and Sandoz), have plowed billions into the dream. If these companies are right, within five years farmers will be planting cotton that is naturally colored to reduce the need for dyeing, as well as crops that harbor plastic. Growers will be armed with higher-yielding, bug-resistant crops. Consumers will pick up from supermarket shelves healthier and more nutritious foods that come from genetically modified plants. Further in the future, children will get vaccines through bananas or other foods, avoiding the terror of needles *(see "Making Needles Needless," page 66)*.

factories in the fields

THE FIRST TRANSGENIC CROPS WERE planted on a large scale in the United States two years ago and have quickly taken root in the economy. This year, genetically altered plants will make up about 15 percent of the U.S. corn harvest, about 30 percent of the soybean crop and more than half of the production of cotton. This first generation was begotten through the relatively simple trick of inserting a gene from a bacterium into a plant to produce a single trait; the results of such work include corn and cotton resistant to specific pests, as well as crops that tolerate several types of herbicides.

While this modest genetic tinkering may seem something short of a biotech revolution, bioengineered crops have taken farmers by storm. "People are surprised at how important the first couple of genes have been," says Anthony Cavalieri, vice president at Des Moines-based Pioneer Hi-Bred International, a leading seller of seeds and a business partner with DuPont. "And this is just the front edge. It could be fundamental to how the whole agricultural sector works."

Indeed, the real payoff is expected to come over the next several years as plant biologists begin not only to insert more genes into plants but also to redraw the genetic blueprints—and redirect the metabolic pathways—of many common crops. The vision is to rewire plants into cheap production units that can grow everything from modified foods to human vaccines to commodity chemicals. The reward for engineering these "output" traits in plants? According to John Pierce, DuPont's head of discovery research in agriculture, it could mean getting a piece of industrial and food markets worth $500 billion per year.

Even for giant corporations, these are not small potatoes. Monsanto, for one, is working on a high-solids potato, as well as canola and soybeans with modified oil content. One strain of canola, for instance, is rich in beta-carotene to combat vitamin A deficiency, which is still a problem in many developing countries.

During the next several years, DuPont expects to begin marketing seeds for modified-oil soybeans as well as high-sucrose soybeans. Working with its partner Pioneer, DuPont has a half-dozen biotech crops nearing commercialization and expects to introduce plants with several traits "stacked" together. The company is also working on high-protein and high-oil crops for animal feeds (about 80 percent of U.S. corn is fed to animals).

Food for humans and farm animals is big business. But an even more lucrative bounty could eventually come from growing biotech crops that make highly prized materials and industrial products right in the plant. Why make synthetic dyes for cotton using highly toxic chemicals, the thinking goes, when the plants themselves could be genetically engineered to produce colored fiber? Why not turn plants into chemical factories?

Plant biologists at Monsanto and a Cambridge, Mass., start-up named Metabolix are separately working on a plastic grown in plants that could be ready for farmers as early as 2002. Prodigene, a two-year-old College Station, Tex., spin-off from Pioneer, is already selling industrial enzymes grown in transgenic corn and is developing other protein-based industrial products. Other labs are attempting to create plants that produce specialty oils that could serve as novel industrial ingredients for coatings and lubricants. Also on the drawing board are plant-based edible vac-

Growing gene information: Cereon's president Timberlake (left) and director of genomics technology Wiegand at work in Cambridge.

Rebirth of a Plant Cell

Step one: To test gene expression, DuPont molecular biologists begin with a suspension of tobacco cells.

Step two: The tobacco cells are smeared out in a petri dish. They're ready for the genetic transformation.

Step three: DNA is bound to particles that are shot into the tobacco cells to insert the genetic material.

Step four: The cells are incubated. The yellow clumps are thriving, genetically modified cells.

Step five: In cell cultures, color intensity indicates at what level the inserted gene is being expressed.

cines for diseases such as hepatitis and diarrhea.

"By tinkering with the control and activity of genes, you can make just about everything in plants," says David Wheat, a longtime plant biotech consultant and president of the Boston-based Bowditch Group. "By understanding how an organism works at a molecular level, you can design new kinds of products—maybe even make products you've never seen before."

simple arithmetic

THE PROSPECTS IN AGRICULTURAL biotech are tantalizing enough that they are helping to drive a massive restructuring of the agricultural and chemical industries that is, in some cases, blurring the lines between the two (*see "Seeding a New Industry," page 39*). Monsanto and DuPont, in particular, have dug deeply into the new opportunities, gobbling up seed suppliers and plant biotech start-ups. Driven largely by the potential of biotech, Monsanto last year unceremoniously dumped its chemicals business, embracing biology as the wave of the future. In turn, this spring DuPont reorganized, forming a life sciences group (which includes its agricultural, drugs and biotech activities) and declaring that its future growth lies in the integration of chemistry and biotechnology.

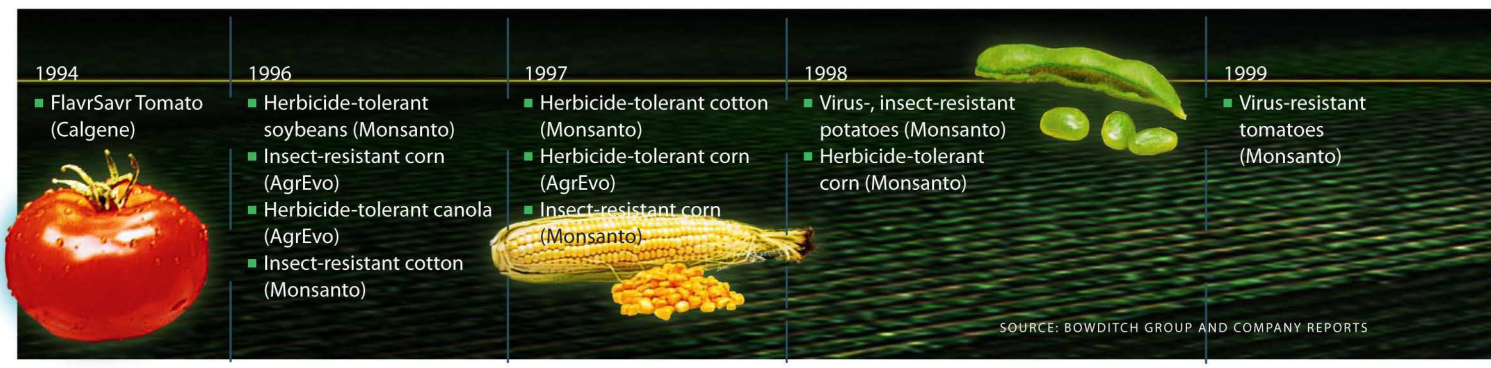
Even staid Dow Chemical, the huge chemicals maker, has professed its desire to be a leading biotech player, targeting the development of plastics and industrial chemicals. "It's a technology whose time has come," says Fernand Kaufmann, Dow's vice president of new businesses and strategic development. Kaufmann cautions, however, that it will take time for plant-grown chemicals to make a dent in the huge commodity markets, which are dominated by products made from petroleum.

It will also take increased knowledge of genes and how to engineer them seamlessly into plants. As an example, take the efforts to make the plastic PHA (polyhydroxyalkanoate) in plants. This polyester material is naturally produced in some bacteria in a distinct pathway involving three key enzymes. To get plants to make the plastic requires inserting the genes responsible for that entire pathway and making sure that the new pathway is integrated into the plant's metabolism.

The possibility of doing this kind of genetic tinkering in plants has changed how plant biologists think, making it possible to conceive of a "perfect" plant—or at least one that makes pretty much what you want. In one notable example, scientists are genetically engineering crops to produce different types of fatty acids (the compounds that make up plant oils). Fatty acids are intriguing because oils can be more easily separated and recovered from a seed than can proteins or starch. Also, modified plant oils could be versatile chemical feedstocks, offering chemists an alternative set of starting materials to those derived from petroleum.

That potentially huge market has attracted the attention of plant biologists around the world. Biologists at the Swedish University of Agricultural Sciences in Svalov and at the Commonwealth Scientific and Industrial Research Organisation in Canberra, Australia, recently collaborated to isolate from wild plants the genes that code for the enzymes responsible for making two important types of biological compounds: epoxy fatty acid and an acetylenic fatty acid. Epoxy fatty acids made from petroleum are widely used in industrial chemistry while acetylenic fatty acids are not commercially available but could prove valuable as, among other things, drying agents in paints.

In separate work, Christopher Somerville, a plant biologist at Carnegie Institution of Washington and Stanford University, has grown plants that make



hydroxylated fatty acids (a type found in castor oil that already has hundreds of industrial applications), as well as ones that produce fatty acids with modified double carbon bonds. Somerville suggests that in the next couple of years biologists will engineer plants that grow designer fatty acids, with chemical groups placed at precisely specified positions along the carbon backbone. The result would be a cheap source of relatively pure chemical intermediates.

The big challenge, says Somerville, is to produce plants that have close to 90 percent of one particular type of oil. "When you can squeeze it out and get essentially one compound, that's when the big industrial applications kick in," he explains. So far, the biotech plants fall well short, yielding at best about 50 percent of the desired oil. But Somerville is encouraged by nature's performance; he points out that castor oil naturally has 90 percent of a single type of fatty acid.

These possibilities are inspiring to corporate researchers. But the reason for the excitement in corporate boardrooms is simple: bottom line arithmetic. Crops like soybeans and corn are cheap. That means that if you can sell seeds for plants that will command a slightly higher value—say, a high-protein corn—farmers will buy them. It also means that a product grown in crops—a plastic in corn for example—can potentially be made much cheaper than those from petrochemical sources. And that differential could become even more attractive if the price of oil rises.

It's that type of payoff that interests DuPont. In addition to using biotech to boost its agriculture business, the $45 billion-a-year company is looking to leverage the technology to revitalize its bread-and-butter activities—making polymers and chemicals. "We're looking for things that will move the bottom line," says Patrick Ireland, a DuPont polymer scientist who

Seeding a New Industry

If sheer size matters, plant biotech will be dominated by a handful of giant corporations. Leading the pack are DuPont, Novartis and Monsanto (which in June declared its intention to merge with American Home Products, or AHP, to form a $96 billion company). Close behind are AgrEvo, Zeneca and Dow Chemical. These companies have gone on multibillion-dollar shopping sprees during the last several years gathering up plant biotech start-ups, genomics companies and seed suppliers.

In the last year alone, DuPont spent $1.7 billion to take a 20 percent stake in Pioneer Hi-Bred International, a large seed supplier. Monsanto paid $2.5 billion for DeKalb Genetics, another seed company, and gobbled up cotton seed supplier Delta & Pine Land. Corporations have also spent heavily on technology, with Monsanto creating Cereon, Pioneer forming a research alliance with CuraGen (a New Haven genomics company) and Dow spending $17 million on a partnership with SemBiosys, a start-up in Calgary that is developing ways to produce proteins in plants. The deals have transformed the agricultural chemicals business from a lucrative but sleepy sector into one capable of revitalizing giant multinational companies. And it has thrust plant biotech into a prominent role—along with pharmaceuticals and foods—in a new breed of "life sciences" corporations.

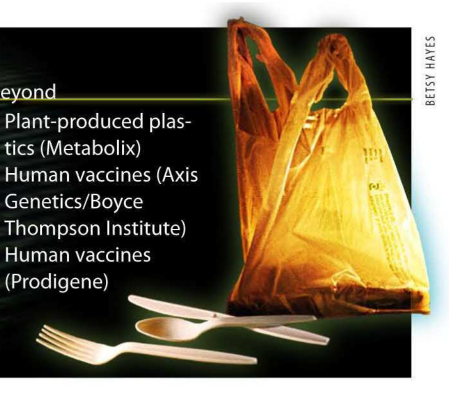
Monsanto, in particular, has staked its future on agricultural biotech in a flurry of deals that culminated with its merger with AHP. The strategy is to use plant biotech as a linchpin holding together the company's agriculture, foods and pharmaceutical businesses. The business plan is straightforward, if ambitious: Control everything from the genetic engineering of seeds to selling the seeds to farmers to marketing plant-grown drugs, modified foods and industrial products.

While some pretty savvy companies are spending billions on this vision, no one really knows whether they can pull it off. The uncertainty lies in trying to define an industry that is attempting to be a hybrid of the chemicals, foods and agricultural businesses. "You've got a totally new technology that is radically different from before," says David Wheat, a plant biotech consultant at the Bowditch Group in Boston. "People tend at first to use technology in a very conventional way, not getting very far away from the obvious." While Monsanto and DuPont believe they know how the new industry will look, he says, not everyone else displays "quite the same vision."

And grand technological advance hardly guarantees business success. Plant biotech's first product, the slow-to-rot FlavrSavr tomato sold by biotech company Calgene and commercialized in 1994, was a flop that failed to excite consumers. Farmers have been more accepting of corn, cotton and soybeans designed to be insect-resistant and herbicide-tolerant. But marketing biotech foods to consumers and turning plants into factories could take time—and marketing imagination.

"The technology is all as exciting as the devil," says Charles Arntzen, director of the Boyce Thompson Institute for Plant Research in Ithaca, N.Y. But Arntzen adds that it's difficult to predict which biotech foods consumers will be willing to pay for. "All of us in the research community are looking at the capability to make products that people can't resist," he suggests. "But there seems to be a huge chasm between the users and the researchers. No one is jumping up and down demanding these products."

2000	2001	2002	Beyond
■ High-lysine soybeans (DuPont) ■ Modified-oil soybeans (DuPont) ■ High-sucrose soybeans (DuPont)	■ Disease-protected potatoes (Monsanto) ■ High-methionine soybeans (Monsanto) ■ Specialty proteins (SemBiosys)	■ Improved-fiber cotton (Monsanto) ■ Colored cotton (Monsanto) ■ High-yield corn (Monsanto) ■ Plant-produced plastics (Monsanto)	■ Plant-produced plastics (Metabolix) ■ Human vaccines (Axis Genetics/Boyce Thompson Institute) ■ Human vaccines (Prodigene)



BETSY HAYES

Hot times for plants: DuPont's Stine-Haskell Research Center grows experimental plants in rows of greenhouses (top) and at a 135-acre experiment farm (below left). Genetically modified corn is bagged (right) to prevent cross-pollination.

heads research into plant-based production of materials. "We're not looking for small opportunities. We're looking for things that aren't accessible easily by standard chemistry."

Because this area is clearly very hot and competitive, Ireland declines to describe the specific compounds his group hopes to make in plants. Instead, he pulls out a spool of thread that has been synthesized using genetically engineered bacteria. It has the feel of silk—velvety soft, but tough. It may or may not be a good target for plant-based production, says Ireland. But it's clearly the type of intriguing new material DuPont has in mind.

Some of the most promising candidates for plant-based routes are polymers that have proved too expensive to make through petroleum-based chemistry, says Robert Dorsch, director of biotechnology development in the company's central research organization. "DuPont has over the years looked at a huge number of different polymers but only makes a handful, and the real reason is the economics of getting the starting materials." Ultimately, says Dorsch, DuPont expects plants to "provide a new palette of starting materials," enabling the company to mass-produce "a much broader range of polymers."

Scott Tingey, director of DuPont's genomics program, says technology has had a profound impact on the field. "A few years ago, it took two man-years to clone a plant gene," Tingey says. "About half the time you were successful, the other half you fell on your face. Today, life is very different." Over the last two years, DuPont has created a database of DNA sequences for corn, soybeans, wheat and rice. "It eliminates the tedious gene discovery process. That's no longer the rate-limiting step in a project," explains Tingey.

Biologists anticipate completing the sequencing of *Arabidopsis* (a weed that is the primary genetic model for plant genetics) by 2000, as a result of an international collaboration that began in 1989. That could be crucial because all flowering plants have essentially the same set of genes. "Within the next five years, we'll know the function of all plant genes at some level," predicts Stanford's Somerville. "It's a major change. We'll be in a lot better position to make rational improvements in plants."

DuPont's research labs are ground zero for modern industrial chemistry, the place where nylon was invented. Now biology is revitalizing the work done there.

DNA databases

FOR THE NEXT FEW YEARS, LARGE-SCALE production of plastic will remain in the factory, not the field. Even in DuPont's most advanced research projects for plant-based materials, Ireland concedes, scientists are still "unraveling the enzymatic pathways while simultaneously developing all the polymer chemistry. No one really understands how to control and regulate plant gene expression."

But if plant genomics continues to accelerate at its current rate, it may become far easier to reach that goal. Most common crops have a large amount of DNA and about 50,000 genes—roughly half the number in humans. But using fast, automated machines honed for unraveling the human genome, plant geneticists are identifying genes more quickly than botanists know how to cultivate them.

Back at newly formed Cereon, one goal is to turn the sequencing of interesting genetic material into a routine, high-throughput production line. In particular, the company wants to accelerate the process of finding a DNA sequence responsible for a specific phenotype, or physical trait. "We are setting up systems that will allow molecular geneticists to go from a phenotype of interest to having a cloned gene, and knowing the sequence for that trait, in a very short time," says Cereon president William Timberlake. "It now takes years to get at some of these genes," Timberlake explains. "We would like to reduce that to weeks or months."

But gathering all that gene information is only the first step. Oliver Peoples, co-founder of Metabolix, explains: "What do you do with all the gene information from genomics? You begin to engineer pathways to optimize the flow of carbon. It's the end use of genomics—it's the ultimate jigsaw puzzle." In other words, the dream is to control the entire metabolism of a plant.

Companies intent on turning crop plants into factories are working on some preliminary steps. DuPont intends to sharpen its biology skills by making a plastic intermediate from sugar using genetically engineered microbes in a fermentation process. The intermediate is the key ingredient in a novel polymer that could compete with nylon, and the company plans to have a small-scale production facility up and running by late 2000. It will be DuPont's first attempt at a biologically based production process, and, says Dorsch, it will guide the company's plans for using biology to make materials.

Against one wall of Dorsch's office is a diagram mapping the metabolic pathways in a bacterium. It resembles a chemical engineering flow diagram—the kind you see everywhere at DuPont—only it's far more complex. The idea, Dorsch says, is to take advantage of the natural flows of carbon in the organism and to engineer subtle changes that allow you to siphon off a desired product. "Organisms are already tuned up to work very well. If you try to move a significant fraction of the carbon through a different pathway, you are getting toward having to completely re-engineer the beast. I don't think we're so audacious as to believe that that is something that will happen any time soon." He quickly adds, "But we might get there."

The DuPont research labs on the outskirts of Wilmington, Del., are sacred ground for polymer scientists and chemists. They are ground zero for modern American industrial chemistry, the place where nylon was invented. And petroleum-based chemistry has long reigned here. Now, says Ireland, biology is "revitalizing" the research. "The polymer chemists are excited about it because they see the possibilities inherent in the science. The biologists are excited because they see the opportunity to use their talents to make a lot of money for the company."

Towering distillation columns are still more common than cornfields in Wilmington. But if DuPont and its rivals are successful, the gap between the agricultural markets and the chemical industry could soon be about to close. Indeed, the gap between industrial chemistry and biology already has. ◊

MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

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The visionary who dreamed up hypertext has never delivered any software...until now. Will ZigZag pass the test? BY STEVE DITLEA

He coined the terms "hypertext" and "hypermedia," and long predicted the universal knowledge repository we now know as the World Wide Web. So why hasn't Ted Nelson gained the recognition due one of the pioneers of the Information Age? Rather than being celebrated by the digerati, Nelson, currently a visiting professor of environmental information at Japan's Keio University, is an exile from an American technology community that has largely shunned him.

His situation may have something to do with his constant, merciless critique of the state of computing, vexing just about everyone in the industry. That many of his perfectionist's complaints are on target makes his words even more stinging. But it could also be the fact that in a 38-year epic quest to create Xanadu, his ultimate electronic publishing system, he has never managed to actually release a piece of software. Until now.

Ted● Nelson's BIG Step

PHOTOGRAPHS BY SILVIA OTTE

No metaphors, no icons, no applications. ZigZag is a Tinkertoy world for users to share, explore and reconfigure.

"One of the reasons I was bursting to tell you about this is it's the first software deliverable I've ever had," Nelson declares to a roomful of complete strangers at the 1998 International Conference on Wearable Computing at the Hyatt in Fairfax, Va. At 60, Nelson is still boyishly enthusiastic, owlishly handsome and as full as ever of show-biz bravado, befitting the offspring of actress Celeste Holm and TV and film director Ralph Nelson. Wearing a tuxedo, a hip pouch-sized PC on his belt and a Cyclopean head-mounted display, Nelson demonstrates ZigZag, his new software paradigm for organizing personal and professional data.

Holm and Nelson Celeste Holm won the 1948 Oscar for Supporting Actress for "Gentleman's Agreement"; Ralph Nelson was nominated for a 1963 Oscar as director of "Lilies of the Field."

Not, of course, before availing himself of a few broadsides against contemporary computerdom. "Software as we know it has become a nightmare. Something happened on the way to computer liberation," he says. In the next 10 minutes he rails against software applications with incompatible file types that cut users off from their data ("an obscenity!"); the myth of the Macintosh ("They took some very good work that had been done at Xerox PARC and nailed it on the world like a coffin lid"); and the metaphoric representation of sheets of paper on computer "desktops" ("It limits us to the connective structure of paper").

At long last, Nelson, the perennial gadfly, can demonstrate a concrete alternative to this computer tyranny: "We are going to see a piece of software which represents a new topology of information," he announces. He's had to wait nearly two decades to introduce ZigZag.

Two Decades The design for ZigZag has been percolating in Nelson's brain since the 1980s. It took until 1998, he says, to find an able programmer who shared his vision to actually implement it. Australian Andrew Pam wrote the current demo version.

Demo Version The program is available as shareware on the Web at http://www.xanadu.net/zigzag/zzdemo.zip in about 1,000 lines of Perl 5 code, running under the Linux operating system. Later planned versions will run directly under Windows or on the Mac.

ZigZag is to numerical spreadsheets, business databases and other applications what hypertext was to text—a fundamentally new, if initially disorienting, principle for organizing information. Think of it as a software designer's Tinkertoy set with any given unit of information—or "cell"—a hub for countless links to other cells that can be programs, data, electronic post-it notes, you name it. ZigZag offers a multidimensional framework for software tinkerers to reinvent word processing, databases, even graphics applications. What's more, ZigZag allows for entirely new ways of tying data together, though it will need a lot more work by skilled software adapters—much as Nelson's ideas for hypertext had to await at least partial implementation in Apple Computer's HyperCard and Tim Berners-Lee's World Wide Web.

The demo itself is as unslick and non-hypermedia as modern computing gets. Projected against a Spartan black background, two side-by-side white-bordered windows display short bits of text linked by lines in white or yellow or highlighted with a green or blue cursor. The left-hand window is for menus. The right-hand window shows the selected cells along any three of many organizing axes or dimensions.

"What we're looking at is a cellular system. We use cells for everything," Nelson explains. He keys through an example showing a three-dimensional arrangement of personal expenses, selecting cells' content by month, day and type of expense, easily appending new data such as the cost of a long-distance phone call and then accessing a list of telephone numbers to identify the person called. In a spreadsheet with "integrated" database functions like Excel, it's necessary to adhere to certain formatting conventions when creating files; ZigZag, as Nelson demonstrates, is truly free-form. He gets a laugh when he waxes metaphorical: "This is the sexual revolution brought to the spreadsheet. In a spreadsheet, society required that a cell have an up connection, a down connection, a left connection and a right connection. In this system each cell's connections are its own business."

He posits other uses: as an outliner for writing, or for control panels on cameras and other consumer devices, providing easily grouped and branched options, like spokes on interconnected wheels instead of the exclusionary choices often encountered on menu- or icon-based readouts. Although the intention is to simplify, Nelson occasionally gets caught up in his own highly detailed vision; he uses with abandon words he invented—"negward" and "posward"—without pausing to explain.

"This whole thing is extremely consistent," he reassures his audience. "By rotation and stepping, you can go to all levels of a complex and rational universe....This is a radical and principled basis for software. No metaphors, no icons and, best of all, no applications, for a totally explorable, customizable, user-reconfigurable and shareable world." Applause.

After Nelson's remarks, the audience tries to come to grips with his new vision. Various questions attempt to place ZigZag in the context of a Microsoft-dominated computer environment, liken it to object-oriented programming, and suggest he start from scratch without a Linux/UNIX underpinning. None of these attempts seems to work, though, because ZigZag really does look like a different approach to computing—one that could change the PC's functionality as much as hypertext has. But despite Nelson's promises of a commercial launch, ZigZag is still more principle than product. When the final questioner asks about how he intends to attain commercial success, Nelson responds: "Trying to take over the world is a mistake. Trying to find like-minded individuals who would like to use your stuff is the way to go."

If only Nelson had learned such restraint earlier in his career. Ever since his student days, when he was gripped with the idea of improving on paper as a literary

Student Days Nelson earned a BA in philosophy from Swarthmore College in 1959—he was almost expelled for his precocious arguments in favor of sexual liberation—and a master's in sociology from Harvard in 1963.

medium, he has held out for his no-compromise, new world information order—Xanadu. Since 1960 when he first envisioned computer networks as storing all of human knowledge, through his going public in 1965 with his ideas for hyperlinked text and media, all during his self-publication of the first personal computer book and beyond the late 1980s when he worked with graphics software publisher Autodesk, Nelson would settle for nothing less than Xanadu. Never mind that for much of his life computer memory and network capacity were so scarce and so expensive that his ideal structure for worldwide publishing couldn't be implemented. Except for a nearly released version withdrawn at the last minute in favor of a never-completed "improved" rewrite, the world at large never got to see Xanadu.

Throughout this period, others would read Nelson's words and be inspired to actualize some small part of his vision in releasable software—occasionally with great commercial success. Ray Ozzie, creator of Lotus Notes, the leading program for collaborative work at the enterprise level, remembers: "During the time that I was pulling my thoughts together for what would eventually become Notes, Ted's thinking was quite influential. The concept of using the new and wonderfully 'personal' computer for shared thought and collaborative process augmentation was a bit antithetical. His work gave me confidence that thinking differently was actually an okay thing to do, even if I couldn't fully grasp where it was all going to end up."

Xanadu was intended to link virtual documents from text or audio-visual elements widely dispersed on a computer network with easy version tracking, providing for micro-payment of authors' royalties and coordinating copyright, ownership and quotation functions Nelson considers essential to an electronic publishing system—features still not embedded in the World Wide Web.

First Personal Computer Book *Computer Lib/Dream Machines: You Can and Must Understand Computers NOW* appeared in 1974; Nelson published the tome four months before the unveiling of the first commercially available personal computer.

All during his pursuit of Xanadu, Nelson took it for granted that it would be implemented. Such brilliant associates as lead programmer Roger Gregory and nanotechnology pioneer Erik Drexler wrestled with the practicalities of his dream while Nelson blithely acted as if it were just around the corner. In 1989, he testified in Washington, D.C., before a Senate Commerce Committee hearing, chaired by Al Gore, about "the coming hypertext revolution." Back when the Internet was still a rarefied tool for scientists, Nelson predicted: "The dissemination and preservation of prepared information packages that can include graphics, sound, video, statistics, laboratory information and anything else we ever digitize should seem no more exotic to us than the instantaneous delivery of the human voice across the telephone, or the instantaneous delivery of the human comedy by television." Summing up, he said: "The Xanadu system, or something very like it, is inevitable...." That same year, Tim Berners-Lee was proposing to his employer, CERN, the European particle

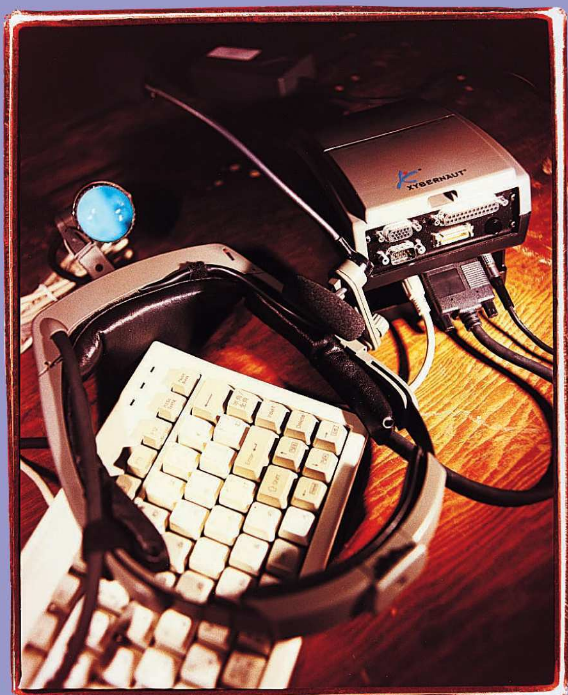
Software for Wearable Computers: Ted Nelson to Go?

The link between ZigZag and wearable computers is an obvious one to Ted Nelson: They're both ways he's long envisioned for making computing accessible to everyone. And indeed, the notion that his new free-form software may end up running on the new generation of hands-free computers may not be far-fetched. ZigZag, Nelson believes, "will lead to a very simple kind of software for wearables—or shall we say 'wearware'?"

Xybernaut, the leading maker of wearable PCs, gave Nelson a 133P battery-powered portable system as an honorarium for his keynote speech at the recent International Conference on Wearable Computing. According to Xybernaut founder and CEO Edward Newman: "The real reason for having wearable computers is so people, wherever they are, can get at the information they need for their jobs, for their personal lives, for their entertainment. Ted's concept of how to get at information is very important to us."

And Nelson is the perfect poster boy for wearables because he may have been the first to conceive of them.

During Nelson's presentation, the video projection screen displays a murky, grey-and-black jpeg photo file. He elucidates: "This is my brother Daniel wearing the Porta-Xan. It was intended to be a wearable computer. It was the size of a large briefcase, with hooks over the shoulders and an awning over the head—a reflective surface going back to a cathode ray tube." According to Nelson, Boston's Computer Museum has been seeking the original 1974 mockup for its collection as the first model of a wearable computer.



Data, data anywhere: Xybernaut's 133P.

physics research center, a project that would become the World Wide Web, the "something like Xanadu" Nelson foresaw—but didn't build.

Against this background of visionary vaporware, the ultimate success or failure of ZigZag may be less important for Nelson than the mere fact that it exists. Ted Nelson has his first nonvirtual software, and that will certainly enhance his credibility—although some will hold him to higher expectations. Already e-mails are streaming in from those who have mistakenly heard that he is demonstrating Xanadu. He's not, but he does say his next deliverable is likely to be a long-promised part of Xanadu: micropayment for authors' royalties, as a commercial product called HyperCoin. As for the copyright tracking Xanadu was supposed to enable, Nelson has spun off a doctrine of public-domain links and limited permissions for use of material on the Web he calls "transcopyright."

Divvied up into more accessible programs, Nelson's vision can finally transcend his all-or-nothing Xanadu, his albatross. "The Xanadu model is so simple, and yet people, instead of hearing it, insist on ridiculing the fact that we never got it out," he laments during a conversation in New York's Tribeca a few days after the Wearable Computing conference. To get more deliverables out now, he is "focused to a narrower plan," he says. "Before there was no telling what to do next because the plan was broad and covered so many directions, and there were no resources."

Although Nelson is now delivering his vision in smaller, easier-to-comprehend programming units, the size of his ambition hasn't changed. He is still building his Xanadu, he's just got a new approach: doing it piece by piece inside your computer. ◊

Transcopyright See Nelson's Web page on "Transpublishing and Transcopyright" at http://www.sfc.keio.ac.jp/~ted/transpub.transco.html

Bell Labs is Dead. Long Live Bell Labs.

This glory of American industrial R&D couldn't survive in its old form. But, confounding its critics, it's still doing remarkable over-the-horizon research.

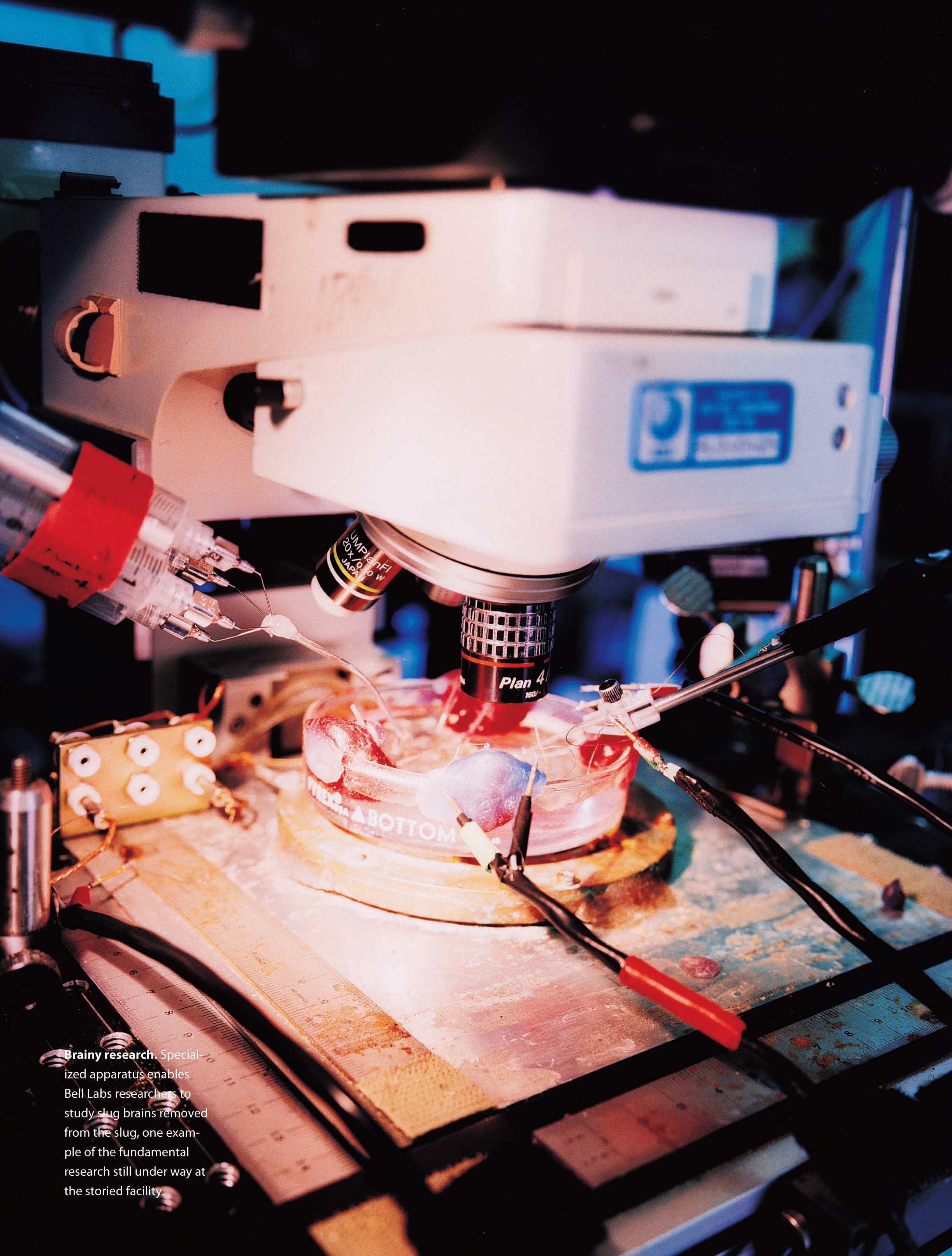
BY ROBERT BUDERI

ALL SEEMS SERENE AT THE LEGENDARY BELL LABS HEADQUARTERS IN MURRAY HILL, N.J. BROAD GREEN LAWNS HIGHlight copper roofs aging into an eye-pleasing aqua-green. A beautiful Japanese-style garden graces an interior courtyard.

But behind this tranquillity lies a poorly understood odyssey of upheaval, transformation—and renaissance. The lab's glorious history—eight Nobel laureates, some 35,000 patents and a tsunami of world-changing inventions from the transistor to information theory—once led many to consider it a national asset. Almost as well documented is the period of "decline," spurred by a much-lamented and highly criticized 1990s makeover that has seen the lab scale back fundamental science and emphasize applied projects and meeting business objectives.

What's missing from the picture, though, is an account of Bell Labs' remarkable resurgence. Changes rocked the lab to its soul over the decade's first half. But now, on the verge of the millennium—and its 75th anniversary—the venerable establishment has reclaimed its place at the forefront of industrial research. Today's Bell Labs is hungrier, faster on its feet, and smarter about business than at any time since the Cold War began, playing a vital role in the success of its upstart parent, Lucent Technologies.

PHOTOGRAPHS BY BERND AUERS



Brainy research. Specialized apparatus enables Bell Labs researchers to study slug brains removed from the slug, one example of the fundamental research still under way at the storied facility.

What's more, basic research has not disappeared, as the critics claim. Scores of scientists continue to pursue dreams that may not pay off for decades, if ever—be it wiring up slug brains to find clues to biological data processing or mapping the universe's dark matter. The critics are right about one thing—pure science doesn't hold the place it once did. And that brings its own kind of loss. Still, by creating novel ways to balance business realities with far-off explorations, Bell Labs may be trailblazing a new era in corporate research.

Ringing Endorsement

LUCENT TECHNOLOGIES, PEOPLE HERE LIKE TO PROCLAIM, IS THE best thing that's happened to Bell Labs in recent memory. It may seem less than earthshaking to outsiders, but chairman Henry B. Schacht's decision to place his headquarters inside the lab and feature the R&D arm in the company slogan provided a ringing endorsement unheard of in the old AT&T days. Chatting in his expansive office, current executive vice president of research Arun Netravali reflects that pride by wearing a polo shirt emblazoned with the message: "Lucent Technologies. Bell Labs Innovations."

Netravali heads the resurgent team. As the hand-picked successor to the lab's former leader, Nobelist Arno Penzias, Netravali assumed daily control of research with Lucent's 1996 formation—well before Penzias retired this spring from the senior scientist's position. But the native of India has been at the lab since 1972. As a Bell Labs engineer and computer scientist, he pioneered digital image and video compression technology—work which last year earned him the prestigious Computers & Communications prize awarded by NEC Corp.

The almost palpable optimism coursing through Lucent is a far cry from the situation only a few years ago, when the lab was thrown for a loop by fast-shifting global competition. Netravali now sees incredible opportunity in the mayhem. Smaller companies and start-ups may move faster and excel in narrow areas, he notes. But Bell Labs' strength lies in the ability to make sense of and shape the bigger picture—by assimilating technologies from inside and outside its confines, and fitting them into systems.

To fulfill this promise, Netravali maintains, the need for speed is paramount—in evaluating projects, pursuing research advances, creating novel products and adopting outside technologies. Another critical focus is "cannibalization"—the drive to make Lucent's own products obsolete. For instance, because of the Internet, tomorrow's data and voice communications will be very different from today's, a potential mega-disruption to traditional business lines. Research has to be ready with solutions. "The key is how can you become an attacker of yourself—almost like another company might do to you," explains Netravali. "Let us become better at doing this than some outside company because it's going to happen anyway."

Bell Labs' critics have a point: the changes there have brought losses. But there's also a new sense of vitality...

These goals could not be adequately met under the old research model—a model that was itself poorly understood. Contrary to popular perception, research has always been a small part of Bell Labs: Of a total workforce of approximately 24,000, only about 1,300 labor on the 'R' side of research and development. However, this relatively tiny endeavor has long served as a fountainhead of science and technology. And for decades following World War II, the emphasis fell on being the first or best: publishing papers, setting transmission records, building the most powerful laser diode.

Bell Labs could afford this Ivory Tower modus operandi largely because AT&T was a regulated monopoly allowed to fold a "research tax" into every phone call and sale. But the Bell System's 1984 court-ordered breakup into seven regional operating companies, AT&T's dramatic decentralization five years later into a series of business units, and then trivestiture, which saw roughly one-fourth of its researchers assigned to the new AT&T, forced a dramatic change in that outlook.

Starting with Penzias and continuing under Netravali, research has moved to reflect the company's new place in a fiercely competitive world. Software studies in object-oriented programming, speech recognition, networking and other fields have been beefed up at the expense of robotics and hard-core physics pursuits such as superconductivity that seem unlikely to have an effect on business. Today the labs are divided roughly 50-50 between the physical sciences and software and networking, a more realistic division than the previous 80-20 split. Meanwhile, in addition to maintaining high standards of excellence, managers have been handed responsibility for meeting the company's technological needs in their particular areas.

Market awareness is central to the new Bell Labs. Scientists and business colleagues interact more regularly with customers and know a lot more about how clients operate than they used to. Since the early 1990s, about half the lab's researchers have worked with business unit colleagues on specific "joint projects." Either side can propose such an endeavor—for creating a new switch, a networking technology, or whatever—that is jointly staffed and developed by research and the particular unit. Up to 50 workers staff each project, though most are much smaller. Specific milestones and timetables are created, and researchers sometimes transfer temporarily to the business unit to help launch the products. There's even a special "breakthrough" category for innovations with strong potential to dramatically reduce costs, improve functionality or create new markets. Typical breakthrough projects get three times a joint project's staffing and seek to slash in half the normal three-year time to market. Such targeted research strategies have produced a slew of lucrative products. Standout innovations run from numerous fiber optics advances to a low-power digital signal processor (DSP) chip to various internet protocol switches designed to route data with unprecedented speed and quality.

Since its inception Lucent has also operated a New Ventures group that helps spin off inventions outside its core areas of focus. "If we do our research work right we're going to create lots of pleasant surprises that are technologically exciting and that make more business sense to commercialize outside of our normal business interests," explains Mel Cohen, vice president for research effectiveness. Under its old style, such products might well have withered on a lab bench. But as of mid-1998, the group had funded nine start-ups based on Bell Labs innovations.

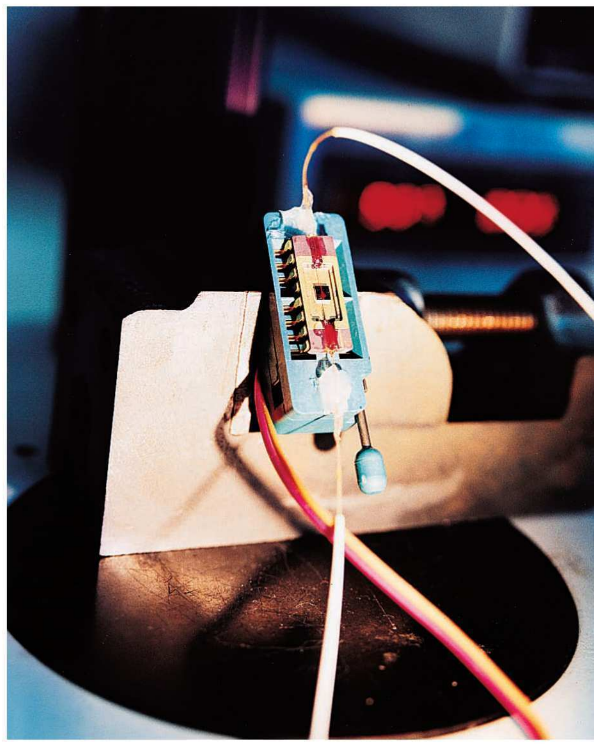
Despite Lucent's soaring success—its stock has risen 430 percent since the initial public offering in April 1996—research managers profess wariness about going too far to the applied side. The great challenge, notes Bill Brinkman, vice president of physical sciences and engineering research, lies in becoming better attuned to corporate needs but not to "overdo it so badly that you have no science."

High Impact

IT'S TRUE THAT "BASIC" SCIENCE STUDIES ARE less numerous than they were in the past and have been scaled back in scope to match more closely areas of core competency—such as lasers, optical communications and materials research. However, the lab is still a place where people from different disciplines mingle in the halls and share ideas through seminars, forums and lectures. And it still harbors an enviable program of over-the-horizon pursuits.

A study of high-impact research papers by Philadelphia-based ScienceWatch showed that in the physical sciences Bell Labs led the world from 1990 to 1997 with nearly 19,000 citations, easily outpacing the 13,020 of runner-up IBM, as well as the world's top academic institutions. "The science there is in the first rate," says Tomihiro Hashizume, a specialist in atomic scale structures who worked at Bell Labs before joining Hitachi's Advanced Research Laboratory in Hatoyama, Japan. The Japanese firm's impressive 13-year-old institution is dedicated largely to basic science. However, says Hashizume, "I think we have to be a little bit smarter to be Bell Labs."

Lucent supports scientific studies for several reasons in addition to gaining a direct competitive edge. One is to create a climate of discovery that attracts top scientists who raise research standards and provide bridges to critical university investigations. Basic research can also act as a broad-based insurance policy, since targeted work naturally focuses on areas that are visibly important—and the future will always hold surprises.



Mini-machines. David J. Bishop heads a Bell Labs department that's working on tiny machines to improve communications systems.

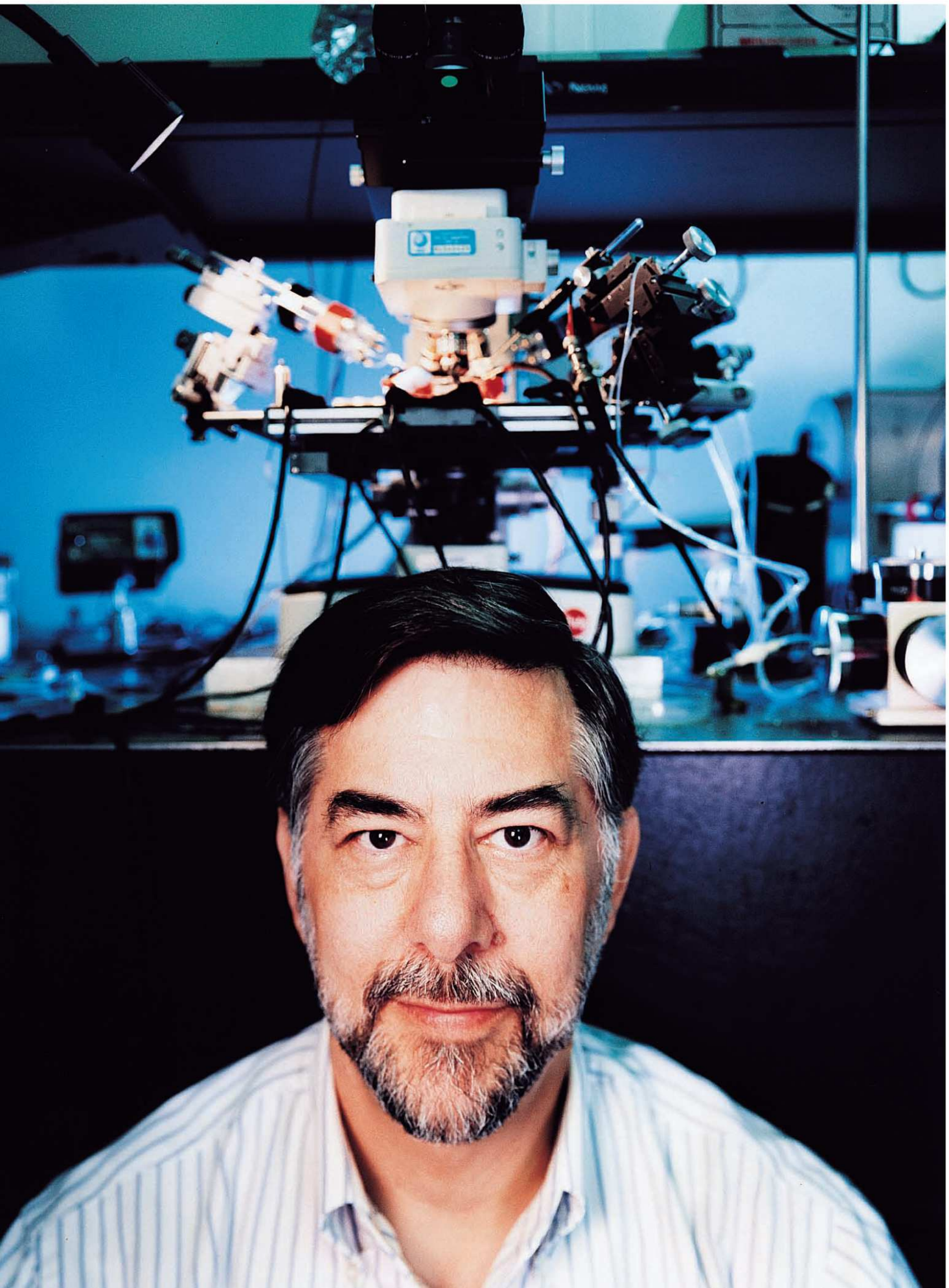
Research is aligned into three divisions that cover a gamut of hardware and software relating to communications: Communications Sciences, Computing and Mathematical Sciences and Brinkman's Physical Sciences and Engineering. All three sustain well-chosen fundamental work. However, when it comes to the lab's hallmark studies in areas such as solid-state physics, most long-range fundamental investigations take place inside the Physical Research Laboratory run by Cherry A. Murray (*see page 55*), part of the Physical Sciences and Engineering division.

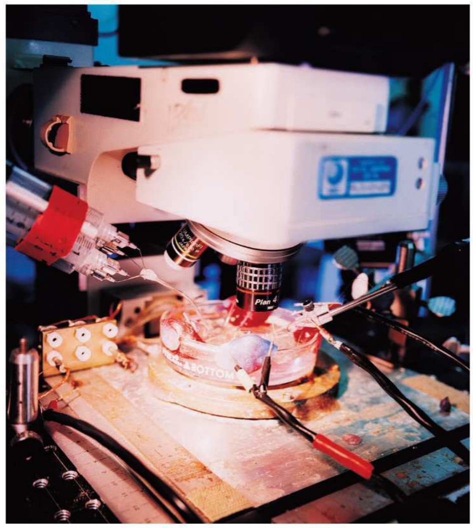
Staffed by about 140 researchers, the lab's activities span physics, materials science, chemistry, computer science, biophysics and astrophysics. Nearly half the efforts look more than 20 years down the road—with virtually all the rest spanning 5-to-10-year horizons. The hope is that all will ultimately bear fruit. In the meantime, it's expected in the new climate that researchers should be ready, willing and able to bring their expertise to bear on more pressing problems that might arise. Even within this framework, however, there is a striking variety in how closely related the research is to business objectives—as three examples show.

Dancing on the Head of a Pin

FROM THE BEGINNING, THE LAB'S WORK ON MICRO-ELECTRO-mechanical systems (MEMS) was set up to have both near-term and long-range benefits for Lucent. The goal of this research is to improve communications systems by building miniature machines—microphones, mirrors and more—that are riddled with moving parts but so small that hundreds fit on a pinhead.

The field has exploded in recent years. Because MEMS devices can be fabricated like an integrated circuit on "last generation" equipment, they can conceivably be made for pennies—and thereby become ubiquitous. MEMS sensors already control automotive air bags, and futurists picture these micromachines driving button-sized cell phones that fit on a lapel, or buildings that sense stress changes caused by an earthquake and adjust their structure accordingly. Lucent won't be making air bag sensors or





Hardly sluggish. Alan Gelperin is the proprietor of the Slug Emporium, where the creatures' brains are observed to study learning and memory.

smart steel. However, explains David J. Bishop, who heads the Microstructure Physics Research Department, "silicon micromechanics has a huge possibility for impacting lots of technologies we care about— particularly optics, acoustics and wireless."

An early payoff could lie in MEMS-based residential communications systems. The volume of data that can be quickly passed in and out of homes keeps running up against the severe limitations of traditional twisted copper telephone lines. Several schemes have surfaced to ease this problem. Some cable companies, for instance, offer Internet connections over the broadband lines that bring in television pictures. But such alternatives have capacity and reliability limitations, says Bishop. So the ultimate goal is fiber optics, "future-proof" because it offers near-infinite bandwidth with a minimum of maintenance.

Due to copper wire's limited capacity, separate telephone lines now have to be run from the central phone company office to each home. The same strategy with fiber optics would be prohibitively expensive. However, since one fiber optic line can handle thousands of phone and data transmissions simultaneously, it might be possible to run a single line to a neighborhood node, then string shorter lines to individual houses—making fiber optics an affordable alternative to copper wires.

Yet there's still a hitch. Signals are transmitted along fiber optics lines by lasers—power-hungry devices too expensive to provide to every household. Bishop likens the problem to that facing hypothetical explorers on adjacent mountain tops. They communicate by flicking flashlights on and off. After all, that's basically how optical communications works—only using lasers instead of flashlights. But suppose flashlights are so expensive only one explorer can afford his own. Two-way communications could still be maintained if the flashlight owner leaves his light on—allowing his counterpart to wield a mirror and reflect rays back to the other mountain in a recognizable pattern.

That's where MEMS comes in. Data would stream into homes in the usual way. But micro-mirrors invented by Jim Walker and Keith Goossen would reflect light back to the central station, simulating lasers in every household for a fraction of the price. Bell Labs has already built mechanical mirrors that can handle in excess of 10 megabits of data per second, nearly 200 times the capacity of today's 56-kilobit-per-second high-speed modems. Says Bishop, "It is our hope that there will be some limited field trials in the next year."

Making Scents

IT WAS EASY TO ENVISION FROM THE OUTSET HOW THE MEMS research related to Lucent's business goals. But other Physical Research Lab work has a more tangential relation to the bottom line and may take many years to pay off. Take Alan Gelperin, proprietor of the Slug Emporium, a bank of refrigerators crammed with the slithery beings. A 17-year lab veteran, Gelperin is a computational neurobiologist and neuroethologist, meaning he studies the algorithms nerve cells use to produce behavior. He concentrates on slugs—snails without shells—because the creatures possess an intriguing ability to rapidly and reliably learn about odors, and because this "learning" continues even after their brains have been removed from the body for experimentation.

Gelperin works primarily with *Limax maximus,* the spotted garden slug. The key to devising models that can be simulated in software or even wired into a machine lies in physiological experiments designed to get at how slugs store and access their odor memories, then take action based on their experience with certain scents. In collaboration with colleague Winfried Denk, Gelperin studies dyed slug neurons through two-photon scanning, a microscopy technique that allows him an unprecedented view of the activity inside the processes of single nerve cells.

Similarly, by applying dyes that change their fluorescence if the voltage across the cell membrane changes, he and researcher David Tank, head of the Biological Computation Research Department, have detected electrical waves and oscillations that originate at one end of the odor-analyzer circuit called the procerebral lobe and propagate along it—starting over again as the previous signal dies out. One hypothesis is that the wave acts as a kind of time stamp for storing data. That is, with the detection of an odor and an associated stimulus—a shock, for instance—the memory of that odor is stored in a specific band of cells that run perpendicular to the wave. "Where the wave is determines where the memory storage is going to happen," Gelperin suggests. The next time the slug is exposed to the odor, it accesses the cells at the same point along the wave—and orders an appropriate response, like gliding away from an odor previously paired with shock. Many experiments remain to be performed before this hypothesis can be confirmed—and possibly incorporated into tomorrow's neural networks.

> Special breakthrough projects get extra funding and people...they aim to cut the time to market in half.

But long-range studies are not the only thing Gelperin does. Working with AT&T's NCR unit before it spun off as a separate company under trivestiture, he used his expertise in neural networks to develop an electronic nose for automated checkout machines. Electronic checkers have little trouble reading bar codes, but they run into real trouble trying to tell a banana from an orange. Gelperin worked with Bell Labs researcher Sebastian Seung, a neural network and machine learning theorist, to create a system that emits a vacuum pulse to pull odors over special sensors that can tell broccoli from lettuce. Last November, Gelperin received a patent on the device.

Gelperin delights in being able to apply his knowledge of neurobiology to solve real-world problems. But he acknowledges that not everybody at the labs has accepted the need to apply their scientific findings. "Some folks just didn't want to think that way," he says. "They had their pure science, and pure was with a capital 'P.' And they just didn't want to be bothered."

90 Percent of the Universe

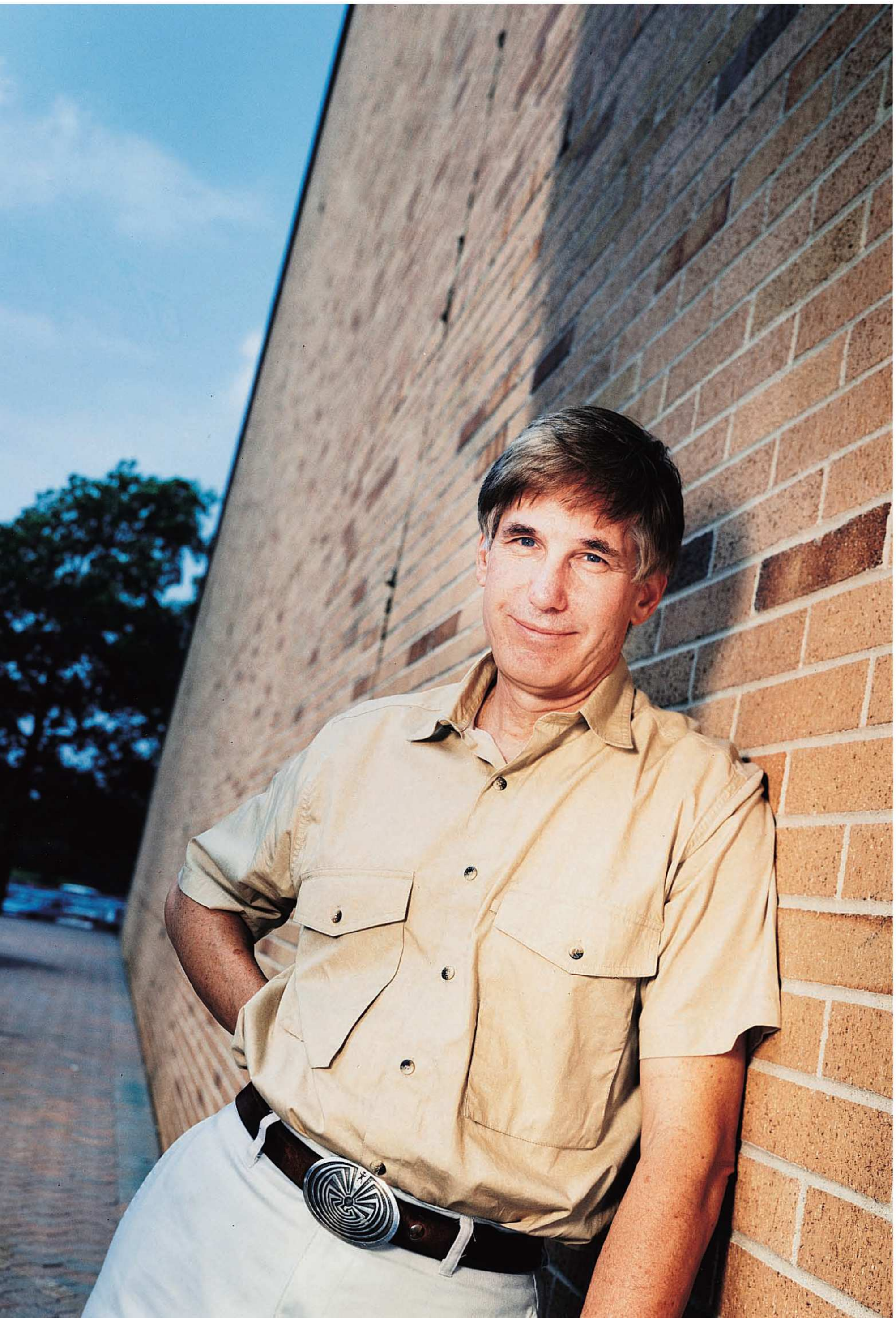
IF GELPERIN'S RESEARCH IS A FRUITFUL MIXTURE OF THE BASIC and applied, Tony Tyson's seems, at first blush, to be purely fundamental. Tyson is one of the world's pre-eminent astrophysicists. When his name comes up, Cherry Murray deadpans: "He's discov-

ered 90 percent of the universe—what can you say?"

Her statement is only somewhat glib, since what the Bell Labs researcher has done is find a way to image cosmic dark matter, the invisible "missing mass" thought to make up some 90 percent of the universe's total mass. Tyson has made a start on filling in the details. But, he figures, "at the rate we're currently going it will take me another 50 years."

The idea that invisible dark matter exists has been around since the 1930s. But the theory attracted only a fringe following until the late 1970s, when modern techniques proved that the visible universe doesn't contain nearly enough mass to explain the movements of galactic gas and dust—a sure indication something else is out there exerting a strong gravitational effect. Early theories tapped neutrinos for the missing mass, but these particles have since been ruled out as major players. Tyson's bet is for a combination of unfamiliar objects and events, including weakly interacting massive particles, or WIMPs, magnetic entities called axions, cosmic strings and breakdowns in the uniformity of the space-time continuum.

The 29-year veteran of Bell research has been hunting cosmic dark matter since 1977. "I'm a prospector," Tyson says. "I should have a donkey, a hat, a canteen and a pickax." His work makes use of what are called gravitational lenses to map this invisible dark matter. Any mass exerts a gravitational pull that bends or deflects the light from something behind it with respect to an observer. It's a very imperfect lens—like looking through a Coke bottle. So, if something lies between the Earth and some distant galaxy, for example, astronomers equipped with the right camera sensitivity and processing software will detect multiple images of that galaxy. The distribution of those images makes it possible to figure out how much mass is out there affecting the light.



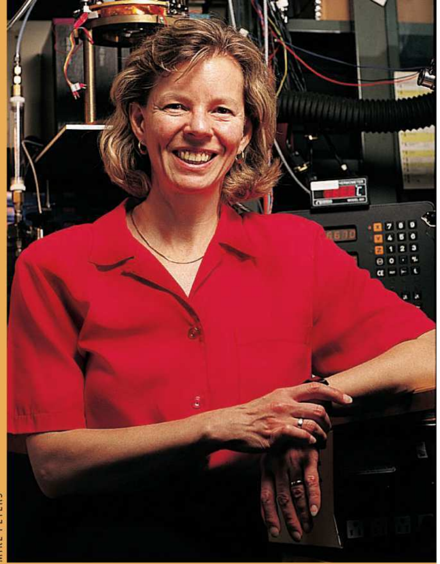
Dark matter often congregates around visible objects like galaxies. In one of Tyson's experiments, the Hubble Space Telescope was trained on a cluster of several hundred galaxies some 2 billion light-years from Earth in the constellation Pisces that seemed a good bet for a gravitational lens. Sure enough, Tyson picked up at least eight images or partial images of another galaxy "behind" the cluster, a systematic distortion that revealed the presence of a good deal of dark matter. Aided by the fact that individual galaxies inside the cluster served as smaller lenses, revealing fine details of their masses, Tyson and collaborators Greg Kochanski and Ian Dell'Antonio created a map showing the distribution of cosmic dark matter at unprecedented resolution. Their map was published this May in *Astrophysical Journal Letters,* with more data to come from Hubble and the special Big Throughput Camera built by Tyson and University of Michigan astronomer Gary Bernstein. Installed on a telescope in northern Chile, it offers 200 times Hubble's field of view.

A Throwback?

TONY TYSON MIGHT SEEM A THROWBACK to the old ways, pursuing a fascination with no apparent relationship to Lucent's business. But even he does not conform completely to the old Bell Labs model. While practicing his basic science, the astrophysicist has also worked on several applied projects. What's more, while

It's around here somewhere. Astrophysicist Tony Tyson calls himself a prospector, since he's looking for the universe's missing mass, also known as "dark matter."

Sibling Rivalry Powers Success!


MIKE PETERS

As a diplomat's daughter, Cherry Murray spent most of her formative years in Pakistan, Japan and Korea. She's lost her Urdu, comprehends only a little Japanese and never did learn much Korean. But along the way, she picked up a more universal language: physics. She taught herself as a high school junior because the U.S. embassy school in Seoul didn't offer the subject. "I was valedictorian," she admits. "But the embassy school in Seoul is not quite the same as the Bronx School of Science."

Even if it wasn't Bronx Science, it proved a good starting point for a long journey in research. Murray enrolled at MIT to study physics, then stayed on after her bachelor's degree to earn a doctorate in the same field in 1978. This career path was a surprise to everyone in her family. Murray's parents are both talented painters (they met in a Taos art colony) who assumed their daughter would become an artist. The main reason she went to MIT, Murray confesses, "was that my brother went to MIT and studied physics, and he said no way would I ever be able to do that."

Well, she did it. (Her brother John hasn't done badly, either: He's chief scientist at the National Ignition Facility at the Lawrence Livermore National Laboratory.) After getting her doctorate, Murray joined Bell's research staff, rising to manage departments in solid-state physics, condensed matter research and semiconductor physics, along the way winning distinction for her studies of colloids. These are microscopic particles that can be crystallized to form structures with unique properties she hopes will lead to new and better optical materials for communi-cations systems.

In June 1997, Murray was named director of Bell's Physical Research Laboratory, a renowned group of about 140 physicists, electrical engineers, biophysicists, biologists, chemists, computer scientists and materials experts whose mission is to explore scientific and technological frontiers a decade or two down the road. Murray is the first woman in the history of Bell research to reach the director level, the organization's third-highest management rank.

After two decades inside the Physical Research Lab, Murray finds herself with a far different mandate than most of her predecessors—not only to produce excellent research but also to have a direct impact on the bottom line. To that end, the lab's fundamental investigations have been targeted on Lucent's core interests, and researchers occasionally work with business colleagues on shorter-range projects. "We're not there yet with the perfect synergy between research and the businesses, and we never will be—but we're certainly far better connected, " says Murray. "We actually know what the stock price is and who our competitors and customers are, where at AT&T 10 years ago nobody had a clue. If we went to a training session, people would say, 'You're from research? You're from outer space.' Now, it's 'You're from research? Oh, I've interacted with so-and-so.'"

hunting cosmic dark matter, he pushed the development of charge-coupled devices for image detection and helped create novel image processing software—advances that have been incorporated into an automated fingerprint detection technology designed to replace locks, and a valuable failure analysis tool that maps the surface temperatures of semiconductors while they're still in production.

Tyson's work—like Alan Gelperin's—can be taken to illustrate how Lucent's attention to applications can pay off. Conversely, it can be used to show that companies should support unfettered science—because far-ranging studies have a way of paying dividends where they're not always expected.

Indeed, the chief complaint from critics of the new Bell Labs is that the drive for relevance has overly constrained scientific inquiries—a strategy that will ultimately cause it to miss the kind of breakthroughs that brought the lab to glory. Many of the critics were drawn from the staff of the lab itself. Morale plummeted during the early 1990s, as the changes were implemented. Scores of veteran researchers quit; so many landed jobs at the University of California, Santa Barbara, that folks back in Murray Hill began calling the school Bell Labs West.

Former Bell Labs researcher Charles Townes, the Nobel laureate inventor of the maser and one of Arno Penzias' instructors at Columbia, understands the reason behind the changes and doesn't know what could have been done differently. Yet he feels that a good deal of Bell's pioneering spirit is evaporating.

The loss is especially lamentable, he says, because more than almost any university, the labs brought world-class scientists together with experts in areas such as electronics or antenna design—producing a tremendous climate of discovery. "Bell Labs was a rather unusual and exceptional place," notes Townes. "For a long time it could be different from other companies because it was a monopoly." Now that it functions like any other company, he adds, "I think it's a great loss for the country."

While agreeing generally with Townes, Tyson says the dynamic for discovery may actually be better now than at any time since the 1950s. An increased focus on relevance has put short-term pressures on researchers and made it harder to pursue "pure" science. However, he states, "I think it's healthy to have this tension. Otherwise you're just sitting in the Ivory Tower doing nothing for anybody. It really does help to be immersed in the needs of the corporation at the same time you're trying to make some new discovery. If you're immersed in other cross streams of technology, of ideas, of demands...that's a very rich environment for completely new ideas to spring forward."

A third perspective comes from Penzias. He agrees with his former mentor Townes that some of Bell's special qualities have disappeared. "There is a lot in what Charlie says, especially in the physical sciences," he admits. "I have to say something has been lost. But that loss is not unique to industrial research. Nothing is what it used to be." Especially not the reborn Bell Labs. ◊

Enter the Dragon

Our future is to speak to machines, thanks to the startup that beat Big Blue to market.

BY SIMSON L. GARFINKEL

"EVERY BUILDING HAS ITS CLAIM TO FAME," SAYS JANET BAKER AS SHE LEADS ME AROUND A THREE-STORY BRICK BUILDing that sits on a hill overlooking Boston. Once a mill, this building has been cleaned, renovated and turned into offices. Today it's the headquarters of Dragon Systems, the company Janet and her husband Jim Baker founded in 1982.

"What's this one's?" I ask.

"The rope that hung John Wilkes Booth was made here," she says with a smile.

Once I know the industrial building's past, the signs are everywhere. The floors on the second and third floor are slightly tilted, so that workers a century ago could roll the massive spools of rope. There are doors on the third floor that open into empty space, where block and tackle lowered the spools to the carriages waiting below. Pulleys and rollers still hang from the building's ceilings.

But historians looking back from the 21st century are less likely to remember this old millhouse for the noose that wrung the neck of Abraham Lincoln's assassin than for being the place where Dragon Systems solved a "grand challenge" of computer science: getting a personal computer to recognize natural human speech.

Ever since the last century, engineers have been trying to build a machine that would heed its master's voice; even Alexander Graham Bell tried his hand at it. And while computers capable of recognizing single spoken words have been around for decades, in the fall of 1995 pundits were still proclaiming that desktop machines capable of transcribing continuous speech—the rapid and sometimes muddled way people actually talk—wouldn't be around until at least the year 2000...and possibly much later.

PHOTOGRAPHS BY FURNALD/GRAY

Fire breathers: Entrepreneurs Janet and Jim Baker stand atop the company they built.

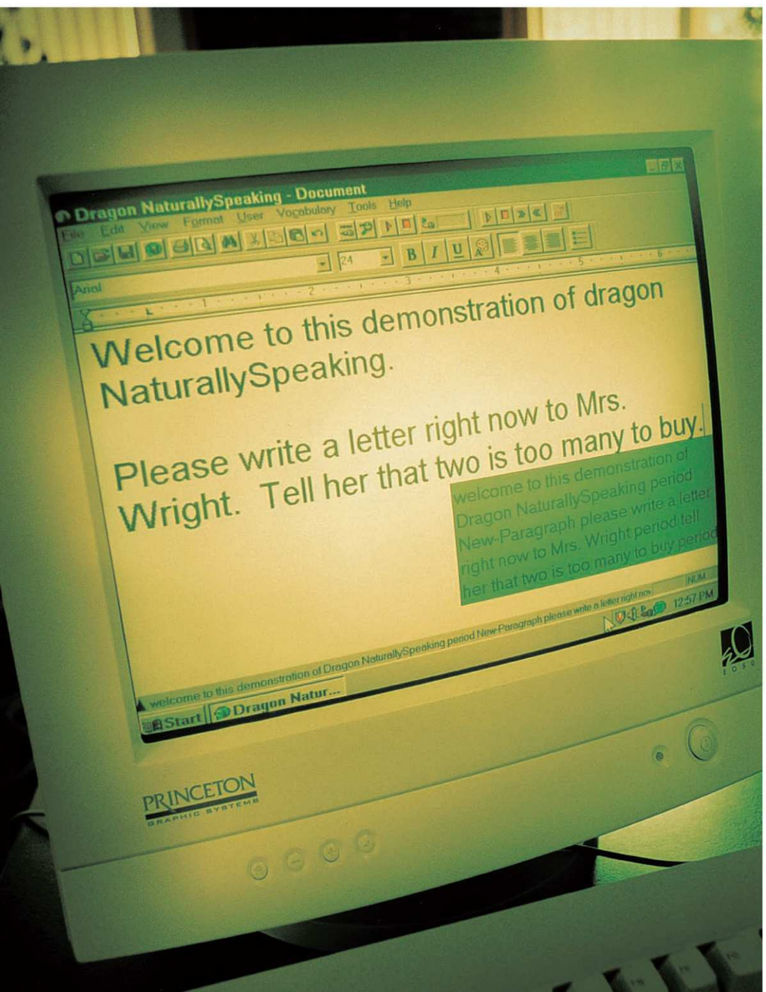
Today, you can buy Dragon Systems' NaturallySpeaking at computer stores for $99.95 and run it on a new PC costing less than $2,000.

So just what can this technology do? Earlier this year I sat in a conference room at Dragon's headquarters with a bunch of skeptical technology writers while Joel Gould, Dragon Systems' lead architect, demonstrated the program he helped create. Gould walked to the front of the conference room, plugged his laptop into the projector, donned a lightweight telephone headset and started talking.

"I am going to give you a demonstration first, and then I will go back and show you some of the things that you saw go by quickly," said Gould. A few seconds later the same words appeared on the screen, typed magically by the computer itself. Gould proceeded in this conversational style, with the machine transcribing everything he said. Although there was an occasional mistake, the machine's accuracy was remarkable. Hoping to stump the program, a reporter asked if it could distinguish between words that sound the same but are spelled differently. Gould smiled, and let out a doozy: "Please write a letter right now to Mrs. Wright. Tell her that two is too many to buy." The system recognized the words perfectly.

Dragon's management confidently predicts that five years from now a computer without such voice recognition software is going to seem as primitive as a computer without a mouse would seem today. Letters and e-mail will be dictated as easily as talking on a phone. Just one step beyond that, PC-based simultaneous translation could topple language barriers.

Speech recognition's arrival a few years ahead of schedule is largely due to the perseverance of Jim and Janet Baker, the couple who founded Dragon back in 1982. As researchers, the pair helped to invent some of the fundamental algorithms used today by all speech recognition products. As entrepreneurs, they fought to commercialize the technology years ahead of anyone's schedule. Now that speech is on the desktop, it's clear that our computing future will be shaped in no small part by Dragon Systems and the husband-and-wife team that gave birth to it.



JANET MACIVER AND JIM BAKER FELL IN LOVE WHEN THEY were both graduate students at New York City's Rockefeller University. It was the fall of 1970. Janet, a personable and outgoing biophysicist, was studying how information is processed by the nervous system. Jim was an intensely shy mathematician looking for a promising thesis topic.

The third participant in their relationship—the riddle of speech recognition—entered the scene one day when Jim visited Janet's lab and saw an oscilloscope screen that was displaying a moving wavy line. The signal, Janet explained, was a "continuous log of ongoing events" produced by a type of small analog circuit originally invented by professor Jerome Lettvin at MIT. The "events" on her screen were the sounds of human speech.

"It struck me as a very interesting pattern recognition problem," Jim says, thinking back on that fateful squiggle. Routed to a speaker, the signal would produce sounds a person could understand: language, in short. But displayed on the screen, the information was impenetrable.

"And as I learned more about it, I learned how difficult the problem really was," he recalls. The key challenge wasn't simply building a computer that could identify individual words—a team at Bell Labs had done that back in 1952. Bell's simple computer could recognize the digits "zero" though "nine" by matching the spoken sounds against a set of patterns stored in analog memory. And by the 1970s, such "discrete" recognition systems—which worked provided that the system was first trained on the speaker's voice, and that the speaker paused between each word—had built up to a few hundred words.

The real task was to design an algorithm that could make sense of naturally spoken sentences—where individual word sounds are camouflaged by their context (*see diagram p. 61*). "That [made] it more interesting," Jim says. Even then, continuous speech recognition struck him as an ideal research problem, which he characterizes as "very difficult but not impossible."

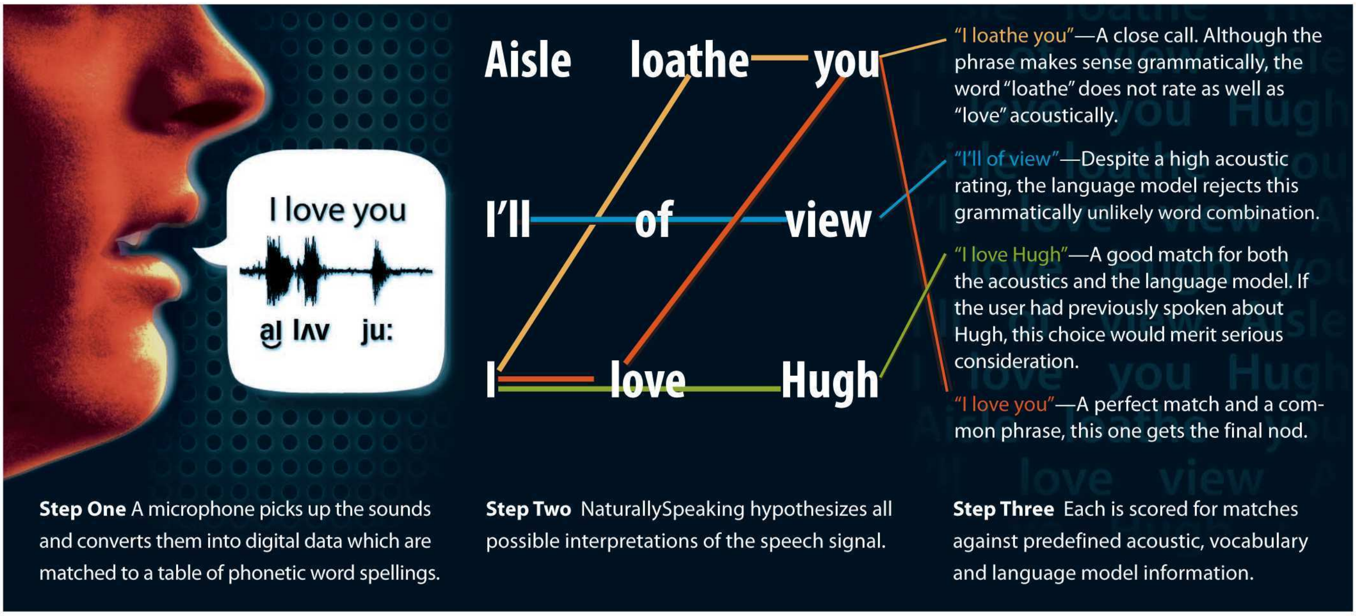
As Jim and Janet prepared for their wedding in 1971, the U.S. Defense Advanced Research Projects Agency (DARPA) kicked off an ambitious five-year project called Speech Understanding Research. The agency felt that any technology that let soldiers communicate faster with computers could be a significant strategic advantage, especially on the battlefield. The project's goal: a system that could recognize continuous human speech from a 1,000-word vocabulary with 90 percent accuracy.

The timing of the DARPA initiative was fortuitous for the Bakers, as was Jim's scientific background. As an undergraduate, he had developed a mathematical technique for analyzing apparently random events, based on methods pioneered by the Russian mathematician Andrey Markov (1856-1922). Jim was the first person to realize that such "Hidden Markov Models" might be used to untangle the speech riddle.

Most newlyweds collaborate to solve challenges such as what

Computers Recognize Speech

Creating software that can recognize natural speech is a challenge because word sounds are highly dependent on context. The most infamous example is "Let's recognize speech," a phrase that sounds just like "Let's wreck a nice beach" when spoken quickly. With the help of Dragon Systems engineer Jeff Foley, *TR* learned how Dragon NaturallySpeaking recognizes the oft-mumbled words "I love you."



BETSY HAYES

pattern to choose for their wedding china. The Bakers didn't skip these tasks (they chose a dragon), but then decided to tackle the problem of speech recognition together as well. Yet they found themselves increasingly isolated at Rockefeller, which didn't have experts in speech understanding and lacked the computer power to try out Jim's techniques. So the next year, they packed their bags and transferred to Carnegie Mellon University, one of the DARPA project's primary contractors and a hotbed of artificial intelligence (AI) research.

At Carnegie Mellon, the Bakers discovered that their approach to speech recognition was way out of step with the mainstream. At the time, many AI researchers believed a machine could recognize spoken sentences only if it could first understand a great deal of context, including who the speaker was, what the speaker knew and what the speaker might be trying to say, as well as the rules of English grammar. In other words, to recognize speech, a machine would have to be quite intelligent.

The Bakers tried a completely different tack. Building on Jim's experience with Markov Models, they created a program that operated in a purely statistical realm. First, they began to calculate the probability that any two words or three words would appear one after the other in English. Then they created a phonetic dictionary with the sounds of those word groups. The next step was an algorithm to decipher a string of spoken words based not only on a good sound match, but also according to the probability that someone would speak them in that order. The system had no knowledge of English grammar, no knowledge base, no rule-based expert system, no intelligence. Nothing but numbers.

"It was a very heretical and radical idea," says Janet. "A lot of people said, 'That's not speech or language, that's mathematics! That's something else!' "

Although the Bakers' thinking met with widespread skepticism, says Victor Zue, associate director of MIT's Laboratory for Computer Science and a fellow speech research pioneer, "time has proved [the Bakers] to be correct in pursuing this kind of approach." Indeed, the Bakers' system, which they named "Dragon" after the creature that graced their china set, soon began to consistently out-perform competing methods.

Other AI researchers thought that only an intelligent machine could recognize speech. The Bakers proved it was a game of numbers.

When the Bakers received their doctorates from Carnegie Mellon in 1975, their pioneering work soon landed them both jobs at IBM's Thomas J. Watson Research Center, outside New York City. At the time, IBM was one of the only organizations working in large vocabulary, continuous speech recognition. "We didn't go to [IBM] and say, 'You have to hire both of us,'" recalls Jim. "It just worked out that way." It was, however, a pattern that would repeat itself. Today, with Jim as chairman/CEO and Janet as president of Dragon Systems, the Bakers take pride in having nearly identical resumes.

At IBM, the Bakers designed a program that could recognize continuous speech from a 1,000-word vocabulary. It was far from

real time, though. Running on an IBM 370 computer, the program took roughly an hour to decode a single spoken sentence. But what frustrated the Bakers more than waiting for time on the mainframe was IBM's refusal to test speech recognition under real-world conditions.

"IBM is an excellent research institution and we enjoyed working there," says Janet. "But we were very eager to get things out into the marketplace and get real users." Certainly real users couldn't wait an hour for a computer to transcribe a sentence. But, she notes, "you could have done simpler things using much less [computer] resources." IBM's management felt differently, and told the Bakers they were being premature.

It was the heyday of missed opportunities at IBM (count relational databases and RISC microprocessors among the key inventions the company failed to commercialize) and in 1979 the Bakers' frustration boiled over. The couple jumped to Verbex, a Boston-based subsidiary of Exxon Enterprises that had built a system for collecting data over the telephone via spoken digits. Jim (as newly minted vice president of advanced development) and Janet (as vice president of research) set out to make the program handle continuous speech.

But less than three years later, Exxon got out of the speech recognition business, and the Bakers were looking for work again. This time, their look-alike resumes spelled trouble—there were no jobs for either of them. The duo realized that they faced a choice: divorce themselves from speech recognition by changing fields, or set out on their own.

In 1982, with no venture capital, no business plan, two preschool-aged children and a big mortgage, the Bakers founded Dragon Systems. They ran the company from their living room, and figured their savings could last 18 months—perhaps 24 if they ate little enough.

A LITTLE HEAVY-SET BUT NOT REALLY OUT OF SHAPE, today the Bakers look a lot more like happily aging academics than successful entrepreneurs. But walking through Dragon's lavish headquarters, it is immediately apparent that they are both. Dragon Systems has grown by nearly 50 percent every year for the past 16; it now employs more than 260 people. Their secret, says Janet, was a decade of self-reliance. Rather than heaping up debt or selling a stake in the company to outsiders, the Bakers insisted that salaries and expenses had to be paid out of revenues. As a result, Dragon focused on solving real-world problems with current technology, and managed to deliver.

The years after Dragon's hatching brought a laundry list of custom projects, research contracts and first-of-a-kind products relying on the increasingly robust discrete recognition approach. Among the landmarks was Dragon's first deal, in which a small British firm called Apricot Computers used Dragon's technology to market the first personal computer to let people open files or run programs by speaking simple commands. (Alas, Apricot had ripened ahead of its time and soon went bust.) In 1986, Xerox workers armed with microphones and radio transmitters used Dragon technology to conduct an audit of the company's entire inventory of 2.2 million parts.

In 1990, Dragon introduced DragonDictate 30K, the first large vocabulary, speech-to-text system for general purpose dictation. The program enabled a user to control a PC using only voice, and immediately found favor among the disabled, including actor Christopher Reeve.

But Dragon's discrete technology couldn't penetrate the general market. Although many people could enter text with DragonDictate faster than they could type, nobody enjoyed being forced to pause between each spoken word. Even worse, competitors were coming on strong with their own discrete speech recognition technology. Everybody knew that what users really wanted was continuous speech recognition, and that the first company to market would be poised to dominate. But everybody also knew that a continuous product was at least five years away, maybe even a decade.

The Bakers gambled their careers on an unorthodox approach, then risked their company to bring continuous speech recognition to market first.

Then sometime during late 1993, the Bakers realized the conventional wisdom was wrong. Knowing the rate at which computer speed and memory were improving, they calculated that top-of-the-line desktop machines should have the power to do continuous recognition within a few years. Just as the pair had once risked their careers on an outlandish new approach to speech recognition, during the first half of 1994 the Bakers started to remake their company in a bid to seize the opportunity and bring their ideas to the marketplace.

While Jim set up a new development team to build Dragon's first continuous speech recognizer, Janet brokered a deal with California-based hard disk manufacturer Seagate Technologies to buy 25 percent of Dragon's stock. The company used the cash to staff up its engineering, marketing and sales forces. Within a year, Dragon had the largest speech research team in the world—more than 50 scientists and software engineers.

The new continuous product would really be two programs in one. The first, the recognizer, would go about the actual job of converting spoken utterances into English text. The second program was the interface, connecting the recognizer to both the user and the rest of the computer's operating system. If the first half was pure science (building on the Bakers' early work), the second was the frustrating mix of engineering and art needed to turn science into a marketable product.

The trickiest of these real-world issues was making the software run well in a Windows environment. "Windows is awful," laments Dragon's Gould, who took on the critical task of designing the user interface. "It's buggy, poorly documented, inconsistent and pieces of it [are] almost unusable. Yet that's what all of our customers run."

By April 1997, Dragon's team had cleared the key hurdles and started hinting to industry analysts that something big was com-

ing. "We were skeptical," remembers Peter Ffoulkes of the market research firm Dataquest. Then he saw the demo—which sported a vocabulary of 230,000 words. "We were pretty much blown away with the capability. We didn't expect it to be here today, and it really is," says Ffoulkes.

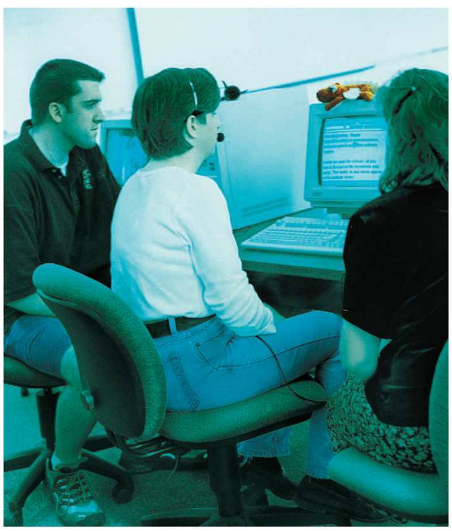
The Bakers had gambled their company and they had bet right. The new continuous recognition product, called Dragon NaturallySpeaking, was an instant hit. Janet Baker's office began filling up with requests from companies hoping to integrate Dragon's technology with their software applications. Articles about NaturallySpeaking appeared in publications all over the world; Gould demo-ed the program on CNN. That fall, NaturallySpeaking swept the industry's COMDEX trade show, winning every major product award.

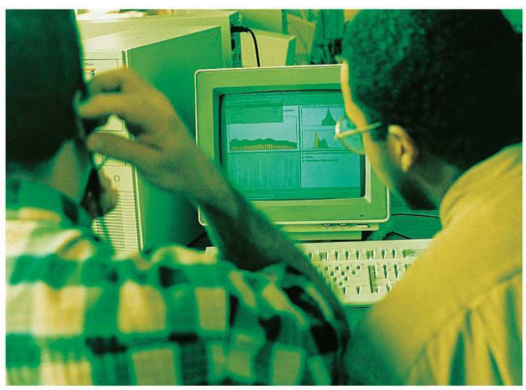
DRAGON'S TIME ALONE IN THE limelight, however, was brief. When the company first shipped NaturallySpeaking in June 1997, IBM responded by slashing the price of its discrete speech recognizer Voice Type, to $49.95. And because word of NaturallySpeaking's impending release had leaked out months earlier, IBM had already launched a crash effort to move its own continuous speech-recognition program (developed in the same lab where the Bakers had worked in the the 1970s) out the door as fast as possible. The product, IBM ViaVoice, hit the store shelves that August priced to move at just $99.

"IBM really blew things away," says John Oberteuffer, president of Voice Information Associates, which studies the speech recognition market. "I have used both of them and as far as pure recognition accuracy I would say they are comparable," he says. Dragon was forced to retrench and slash its price from the hefty initial fee of $700, to $299, then to $199. By the end of the year, Dragon had sold 29,463 copies of NaturallySpeaking, while IBM had sold 46,182 copies of ViaVoice, according to PC Data. But in overall product revenue, Dragon had trumped Big Blue.

IBM and Dragon continue to duke it out for market share, but ultimately Dragon's biggest worry isn't IBM, but Microsoft. That's because speech recognition looks as if it could be a key component of the PC operating system.

"We definitely see, over time, shipping

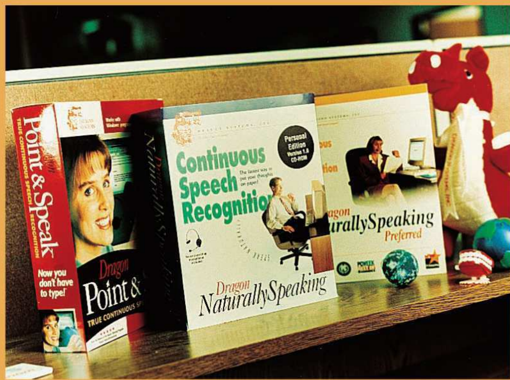




NaturallySpeaking—in tongues: South American software distributors train at Dragon. Native speakers have helped Dragon adapt its software to German, French and Spanish.

How to Talk to Your Desktop

Although continuous speech recognition software is still in its infancy, consumers already have a lot of choices. Less than a year after Dragon brought out the first product—Dragon NaturallySpeaking—it was joined by two aggressive competitors: IBM launched a $99 program called ViaVoice, and Lernout & Hauspie Speech Products came out with VoiceXpress at $49. Dragon's original offering has now been split into four products with Dragon Point & Speak ($59) on the low end, and NaturallySpeaking Deluxe ($695) offering the most features.



All the programs come in a box that includes a CD-ROM, a thin instruction manual and a voice recognition headset. You need to supply the computer—and a fairly powerful one at that. Although Dragon claims its software will run on a PC with a 133 Mhz Pentium processor with 32 MB of memory, I found that the software really required a 200 Mhz Pentium with between 64 MB and 128 MB of memory to perform well.

Once you've installed the software and plugged in the microphone, be prepared to spend an hour or so adjusting volume levels and teaching the program to understand you. Speaker-dependent systems first need to be trained on the user's voice—recognition patterns adjust to individual pronunciation and pitch. Dragon makes this process the most interesting, letting you read selections from Arthur C. Clarke's *3001: The Final Odyssey* and *Dave Barry in Cyberspace.*

After you train the software, it's time to start training yourself. Most people don't have practice dictating. As a result, they tend to drop syllables, slur words or mumble. Unfortunately, the software only transcribes what you say—not what you mean. I find that it takes considerably more concentration to write by voice than by typing. Apparently, this is a problem especially for journalists; we tend to think with our fingers.

But not everyone types for a living. Dragon estimates that the average computer user types at less than 30 words per minute. Using voice recognition programs, most people can dictate at more than 100 words per minute—with an accuracy of between 95 percent and 99 percent.

Using speech recognition software is straightforward: You talk and the programs transcribe your words. Occasionally they make mistakes, known as "speakos." With NaturallySpeaking and L&H's VoiceXpress, you correct these errors using either the keyboard or your voice—just say "correct," then repeat the word that you actually wanted. You can also spell the words. IBM's product, however, requires that you use the keyboard to correct mistakes.

The main problem in using NaturallySpeaking isn't the software itself, but the modern workplace. If somebody knocks on your door to ask you a question, you have to turn off the software before you answer them. Otherwise you'll see your answer appearing in the document. That's because NaturallySpeaking understands words, but it has no idea what the human operator is actually saying. It's still a long way from the HAL 9000 computer.

speech technology...as part of the operating system," says Kevin Schofield, senior program manager of Microsoft Speech Group. Although Microsoft has licensed Dragon's technology in the past, the software giant has now allied itself with Dragon's competitor Lernout & Hauspie Speech Products, investing $45 million in the company and, last June, making L&H's VoiceXpress Plus a partner for Microsoft's much-anticipated Windows 98 launch.

No matter what happens in the world of desktop computers, Dragon plans to take a big bite out of the continuous speech recognition market, which analysts estimate at $4 billion worldwide by 2001. And Dragon's current research projects reveal a wide-ranging vision for the field's future. For example, a translator code named "Bablefsh" could enable a person to communicate with foreigners. Designed for use by the U.S. military in Bosnia, the prototype system is a multimedia phrase book that listens to what a soldier says in English, recognizes the phrase and then plays the matching phrase in Serbo-Croatian.

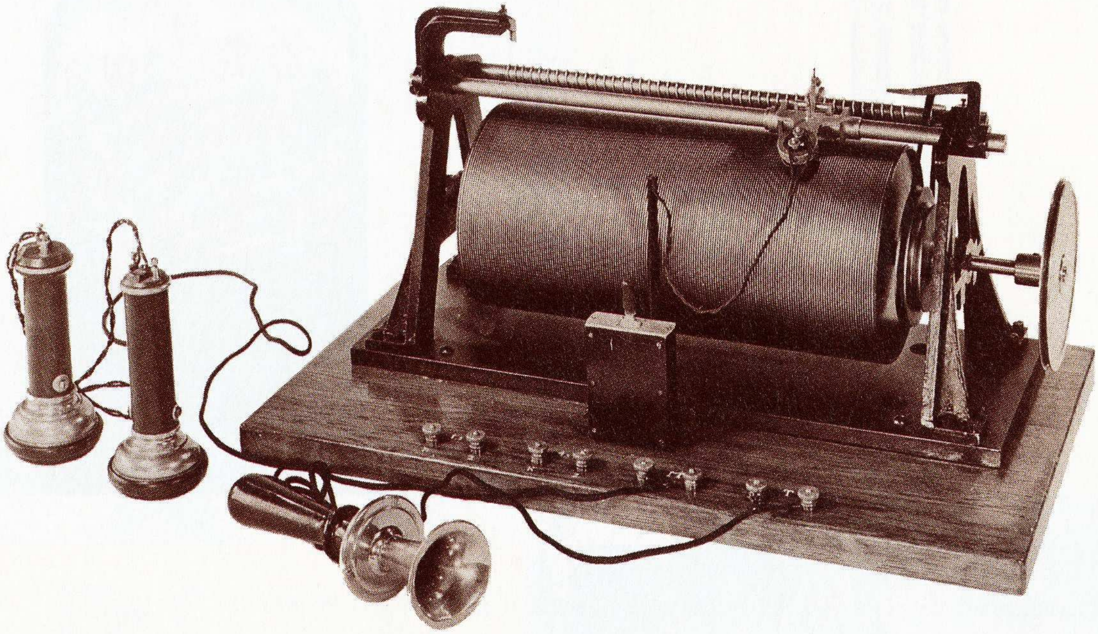
"We took one to the Boston Marathon last year," says Paul Bamberg, Dragon's vice president for research, surprising some Japanese-speaking and Polish-speaking runners with a machine that could chat with them. Bamberg speculates that within five years such simultaneous translation systems could be built into the telephone network: You might be able to call Germany or Russia and speak with whomever answers, regardless of language.

Dragon is also pushing new broadcast transcription methods that could enable a television network to automatically index hundreds of thousands of hours of library footage. The same technology will appeal to cloak-and-dagger types for eavesdropping on telephone lines and scanning for incriminating words such as "cocaine." Still another group of Dragon engineers is devising techniques for building continuous speech recognition into hand-held devices such as cellular telephones. A few years from now, making a call from your car won't require stolen glances at tiny screens and single-handed attempts to enter digits. By then, hand-held computers controlled by voice instead of today's too-small keyboards and clumsy touch screens will be commonplace.

The next landmark beyond continuous speech recognition, explains Jim Baker, "is what we call 'natural speech.'" By virtue of processing power and better algorithms, computers will actually start to hear not just what you say, but what you mean. Such attentive devices won't just understand specific spoken orders, but will actually respond to a whole repertoire of loosely defined commands. They will even know when they are being spoken to, and respond. Ultimately, Jim predicts, nearly "any device that has a processor in it" will understand human speech.

If it all seems like material for Star Trek, the Bakers already have their riposte prepared. Star Trek takes place in the 23rd century—Dragon plans to deliver way ahead of that schedule. ◊

Simson Garfinkel wrote the first draft of this article using Dragon NaturallySpeaking.



New no-needle vaccines can protect against disease without being a pain in the...arm.

Making Needles Needless

BY CAROL POTERA

THE JAB OF THE NEEDLE IS A PAIN, BUT IT PROTECTS US FROM A MULTITUDE OF microbes. Children in the United States endure as many as 14 vaccine injections by the time they're 16. Adults are immunized to ward off influenza and tetanus; travelers arm themselves against cholera, typhoid and other diseases.

Though injection is a time-honored means of delivering the goods, it has significant drawbacks. Injection equipment can quadruple the cost of a single vaccination. Fear of the needle reduces compliance with vaccination schedules in developed countries. In the developing world, reuse of syringes spreads disease, and lack of refrigeration limits the availability of vaccines. Indeed, the severity of these problems recently prompted the World Health Organization (WHO) to declare war on unsafe injections and to urge the development of oral and nasal vaccines.

Injected vaccines reign in part because researchers understand how they work. Introducing a vaccine underneath the skin or into the muscle provokes systemic immunity: Protective antibodies circulate in the blood. Delivering the vaccine orally triggers immunity at moist mucosal surfaces such as those that line the mouth, nose and genital tract, but the process has been far less well understood, says Robert Edelman, associate director of clinical research at the University of Maryland's Center for Vaccine Development in Baltimore. But when the

PHOTOGRAPHS BY KELLER & KELLER

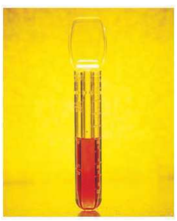
BACKGROUND IMAGE COURTESY OF C. HUMPHREY AND E. PALMER, CENTERS FOR DISEASE CONTROL AND PREVENTION

AIDS epidemic struck in the early 1980s, it forced researchers to begin unraveling the intricacies of mucosal immunity.

In the last five to 10 years, researchers have learned how microbes that enter the body via mucosal surfaces can be blocked by mucosal vaccines. Armed with new knowledge, more than a dozen vaccine technology companies are hoping to render the immunization needle needless and replace it with nasal sprays, nose drops, flavored liquids, skin patches and edible vaccine-laced plants. While some are still testing products in the laboratory, others have already jumped the hurdles of the Food and Drug Administration's (FDA) approval process. Favored to make it to market first over the next couple of years are an oral vaccine to protect children from rotaviral diarrhea and a nasal spray alternative to the flu shot.

Though each new vaccine comes with a research and development price tag of $50 million to $200 million, the potential payback is enormous. The makers of the rotavirus vaccine, for example, project annual worldwide sales of up to $250 million. Another company estimates that customers could shell out several billion dollars each year for a nasal vaccine against *Shigella*, a diarrhea-causing bacterium. For his part, Edelman hopes user-friendly delivery systems will improve the rate of childhood immunization at a time when 1 million American children have not had their recommended vaccinations. "Kids have to get so many shots, it cuts down on compliance," Edelman says. "There's a need for new delivery systems."

A Bouncer at the Door



THE CHIEF TARGET OF noninjected vaccines is the body's vast expanse of mucosal membranes. Combined, mucous cells cover an area equal to about one and one-half tennis courts, lining the respiratory and gastrointestinal tracts, urinary and genital passages—even the eyelids. Mucosal immunity is the body's front line of defense, since 90 percent of infections start at mucosal sites. Such common infections as pneumonia, sore throats, flu, diarrheal diseases, ulcers and sexually transmitted diseases all begin at mucosal surfaces.

The future holds a variety of **no-needle options—** even vegetables could be turned into delivery vehicles.

Mucosal immunization prompts the immune system to produce two types of antibodies in different regions of the body: powerful IgA antibodies at mucosal surfaces, and IgG antibodies in the bloodstream. In contrast, injected vaccines trigger only IgG antibodies in the blood. By eliciting the IgA response, mucosal vaccines protect the body against invading pathogens before they reach and damage internal organs. The protection of an IgG-inducing injected vaccine only kicks in after an infection starts.

A mucosal vaccine could take a number of different forms. Nasal sprays, nose or eye drops, capsules, liquids and rectal or vaginal suppositories are all possible vehicles for vaccination—some clearly more practical and palatable than others. Fortunately, says David Burt, vice president of research at Montreal-based Intellivax International Inc., "the mucosal immune system is interconnected," so vaccines applied at a convenient mucosal site protect other areas of the body as well.

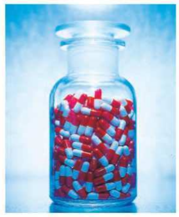
A Shot in the Nose

ONE OF THE FIRST vaccines to make it into patients' nostrils will probably be FluMist, a nasal spray aimed at influenza viruses. Both children and healthy adults may soon get their annual flu "shots" from this syringe-like device with an aerosol sprayer where the needle ought to be. The device delivers a live, but weakened, influenza virus that only grows at the cooler temperatures of the nasal passages. There, the vaccine primes the mucosal immune system to stop disease-causing flu viruses before they can take hold in the nose and upper airways.

FluMist has done well in clinical trials—it provides 93 percent protection against the flu in children, with mild side effects (runny nose or sore throat) that last a day or so. But the new vaccine might also have another—and more positive—side effect. It reduces the rate of flu-related ear infections by 98 percent. Ear infections send American children to the pediatrician more than 31 million times each year, and most of those kids receive antibiotics; vaccinating children against influenza could make a dent in this overuse of antibiotics and the resulting rise of drug-resistant bacteria.

Aviron, the California company that is developing FluMist, applied for FDA approval for the nasal flu shot this summer. The company hopes to make FluMist available in time for the 1999 flu season.

Down the Gullet



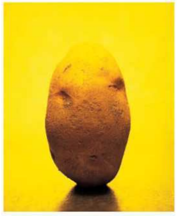
ANOTHER OBVIOUS route for noninjectable vaccines is—down the hatch. But oral vaccines face tough obstacles. They must survive the harsh environment of the stomach and intestines. In addition, the digestive tract sees a lot of "immunological challenges from food," says Peter Nara, president of the International Society for Vaccines and director of R&D at the Maryland start-up Biological Mimetics. As a result, the lining of the tract tends to overlook immune stimuli such as vaccines. Any vaccine operating there is "working against City Hall," according to Nara.

Despite these hurdles, new vaccines against diseases as disparate as typhoid fever and stomach cancer will soon be swallowed. One of the first will most likely be RotaShield, developed to protect young children from the severe diarrhea caused by rotaviruses. Nearly 1 million children die yearly from rotavirus infections in developing countries, and its oral form may make RotaShield easier to distribute in those regions. In the United States, 3 million cases of rotaviral diarrhea account annually for 500,000 doctor visits, 100,000 hospitalizations and 100 deaths, costing the health care system $1.4 billion in direct and indirect costs.

Albert Kapikian and his colleagues began tinkering with the oral rotavirus vaccine in 1980. "We never even considered the possibility of an injected route," says Kapikian, head of the epidemiology section of the Laboratory of Infectious Diseases, part of the National Institute of Allergy and Infectious Diseases. Making an oral vaccine for an intestinal virus "was a natural way to go."

To save the vaccine from destruction in the stomach's acidic environment, children in early studies drank milk (an acid-neutralizer) a half-hour before vaccination. In its final form, the vaccine is freeze-dried, then mixed with a small amount of a salty buffer that protects it. In the gut, the virus multiplies long enough to generate protective mucosal antibodies—the only side effect is a mild, brief fever. "The proof is in the pudding—or the protection—which has been excellent," says Kapikian; the vaccine reduces the incidence of severe rotaviral diarrhea by up to 90 percent. Licensed by Wyeth-Ayerst Laboratories, RotaShield is awaiting FDA approval. The vaccine, which will be recommended for all children at 2, 4 and 6 months of age, has already gained the endorsement of the Centers for Disease Control, the American Academy of Pediatrics, and the WHO.

Vaccine Veggies



AS KNOWLEDGE OF THE mucosal immune system was emerging, so were the genetic engineering tools that enable researchers to insert vaccine molecules into plants. The next logical step was to investigate whether food plants carrying vaccines could immunize the digestive tract. "The tools and knowledge converged that naturally led us down this path," according to William Langridge, a molecular biologist at California's Loma Linda School of Medicine.

Langridge converted the plebeian potato into a cholera vaccine by adding genes for cholera toxin. In mice that ate the raw potatoes, the toxin bound cells in the gut and triggered the production of antibodies against cholera. To make the potatoes more appealing, Langridge boiled small cubes of his special spuds until soft—surprisingly, at least half the vaccine remained active. Flash cooking methods, like deep fat frying, may preserve more vaccine, he suspects. (Imagine getting your vaccination from a bag of chips or a plate of fries.) Langridge's experiments have sparked interest from biotechnology companies, but it's too early in negotiations to identify them, he says.

Potatoes are a dietary staple in Peru, Bolivia and India—countries where cholera causes dehydrating diarrhea and death—so the potato is a "good target plant," Langridge says. He calculated that eating one boiled potato weekly for a month should protect against cholera. Booster spuds may be needed if protection falls. "Food plants move us closer to achieving a low-cost, convenient, effective and safe strategy for prevention of infectious enteric (intestinal) diseases," says Langridge. When grown locally in developing countries, edible vaccines could circumvent problems of transportation and refrigeration that hamper effective vaccination programs.

COMMERCIALIZING COMFORTABLE VACCINES

Some of the companies working on noninjectables

COMPANY (LOCATION)	TARGET MICROBE/DISEASE	ROUTE	STATUS
Aviron (Mountain View, Calif.)	Influenza virus/flu Parainfluenza virus/croup	Nasal Nasal	Applied for FDA approval Phase II
Intellivax International Inc. (Montreal, Quebec)	*Shigella*/dysentery HIV/AIDS *E. coli*/diarrhea	Nasal Nasal Nasal	Phase I Preclinical Preclinical
ID Vaccine (Bothell, Wash.)	Streptococcus A/throat infection, pneumonia	Nasal	Preclinical
OraVax Inc. (Cambridge, Mass.)	Respiratory syncytial virus/pneumonia *H. pylori*/ulcer, stomach cancer *C. difficile*/diarrhea	Nasal Oral Oral	Phase III Phase II Phase I
Berna Products (Miami, Fla.)	*S. typhi*/typhoid fever	Oral	Available now
Protein Sciences (Meriden, Conn.)	*H. pylori*/ulcer, stomach cancer Influenza virus/flu	Oral Nasal	Preclinical Preclinical
Wyeth-Ayerst (Philadelphia, Pa.)	Rotavirus/diarrhea	Oral	Applied for FDA approval
Iomai (Washington, D.C.)	*C. tetani & C. diphtheriae*/tetanus & diphtheria	Skin	Phase I
Inhale Therapeutic Systems (San Carlos, Calif.)	Respiratory tract diseases	Lungs	Preclinical
Axis Genetics (Cambridge, England)	*E. coli*/diarrhea	Edible plants	Proof-of-concept in people

While researchers from Cornell University's Boyce Thompson Institute for Plant Research (BTI) have also experimented with potato-based vaccines, they now are turning their attention to plants more commonly eaten raw. "Potatoes were the proof-of-concept crop," says Cornell researcher Hugh Mason, "but bananas and tomatoes look more promising for human consumption."

In June, BTI announced a research and license agreement with Axis Genetics, a biopharmaceutical firm in Cambridge, England. Axis will back BTI's edible vaccine research for three years, in return for exclusive use of BTI technology.

Back to the Band-Aid

PERHAPS THE MOST REMARKABLE VACCINES in early development are those that cross the skin—as injections do—but without a needle. Several groups, including the Iomai Corp. in Washington, D.C., are working on a painless way to tackle this traditional route. Iomai researchers added cholera toxin to diphtheria and tetanus vaccines and rubbed it on the skin of shaved mice. The combination activates Langerhans cells in the skin, some of the mightiest of known immune cells. The mice built up blood antibodies against both diphtheria and tetanus.

The process, known as transcutaneous immunization, "could be particularly useful given the large surface area of the skin and its potent immune cells," says Gregory Glenn, scientific director of Iomai. Eventually, the immune-stimulating concoction could be incorporated into bandages or patches. Instead of leaving the doctor's office with a Band-Aid over a vaccination stab wound, a patient could go home wearing the vaccine itself. "It's an exciting possibility, but we have a tremendous amount to learn," remarks University of Maryland's Edelman. For example, researchers don't even know just how the vaccine crosses the skin. Studies to test the new method in humans are just starting.

Whether they come in patches, nose sprays, liquids, potatoes or tomatoes, vaccines in the next few years will come with less terror. And safer and more convenient delivery systems will reduce the number of needle-stick accidents (one way that health workers get AIDS) and possibly raise the rates of immunization worldwide. Recently, the Children's Vaccine Initiative—an effort co-sponsored by the WHO, the United Nations, the World Bank and the Rockefeller Foundation—estimated that just a handful of the vaccines currently under development could save the lives of 8 million people each year. With the right delivery systems, none of those people will feel a jab. ◊

> Instead of leaving the doctor's office with a Band-Aid over a vaccination stab, you could go home *wearing* the vaccine.

Vaccines to Market? When the Time Is Right

Timing is everything in life, they say. And that's true even in the field of vaccine development, where it would seem that the only crucial concern is public health. In fact, the widespread adoption of a new vaccine preparation may have less to do with public health than with other factors in the social and medical environment. Take the case of FluMist, the first nasal vaccine for influenza to come before the Food and Drug Administration (FDA).

There has long been a public health need for vaccinating children against the flu, says Brian Murphy, head of the respiratory viruses section at the National Institute of Allergy and Infectious Diseases. Children are infected with the flu virus 10 times as frequently as adults—this is a major cause of the pathogen's spread. But the inconvenience of a shot kept childhood flu immunizations from catching on, says Jo White, vice president of medical affairs at Aviron, the company intent on bringing FluMist to market.

The viral strain used in FluMist was discovered in 1967 by epidemiologist Hunein Maassab at the University of Michigan. Murphy's laboratory worked on creating a vaccine for 18 years. "We worked out the amount of virus needed and the required properties for immunity," says Murphy. In addition, because flu strains change from year to year, Murphy had to prove that his vaccine could be regularly updated to protect against the most current circulating strains.

The new vaccine was finally ready for licensing in 1983, but in spite of the perceived need for the preparation, no company was interested in pushing through the process of FDA approval and then taking it to market. The idea of having to update the vaccine may have made companies nervous, Murphy speculates. Whatever the reason, it wasn't until 1995 that Aviron finally took on the project.

Economics and old-fashioned health attitudes likely kept companies away, says Aviron CEO Leighton Read. At a price of $2 a dose, "there's not enough money to attract R&D investment," he says. Fewer than 20 million people a year received flu shots in the 1980s, compared with 80 million a year now. The rise of preventive medicine—not product innovation—drove this growth. Today flu shots are no longer restricted to doctor's offices; they're available at health clubs, pharmacies, worksites, shopping malls and senior citizen centers. "The growth of managed care, despite all its warts, promotes preventive medicine," says Read. "Today you make money if you keep people healthy." And that new attitude could ultimately have an important impact on the development of vaccines that are more comfortable and convenient for kids.

NICK KOUDIS/PHOTO DISC

That Mess on Your Web Site

Q & A

Jakob Nielsen, Sun Microsystems' guru of interfaces, wants to clean it up—by putting the user first.

In some ways, the most difficult connection on the Internet may be the very last one: between the computer screen and the human mind. Although finicky servers and overloaded phone lines cause their share of problems, the bits usually get delivered. The message, however, often doesn't. It remains imprisoned within a confusing, indecipherable Web page. Viewers of the page follow wrong links. They can't find what they want. They get lost, or they get bored—and they move on.

The hypertext markup language (HTML) used to create Web sites was created less than a decade ago. And as with any language, people learning it must babble for a while before they achieve eloquence. In the meantime, users of the Web struggle to decipher its mangled metaphors and broken syntax.

Jakob Nielsen has made it his business to watch people engaged in that struggle. Nielsen is a distinguished engineer at Sun Microsystems, the computer company known best for its high-powered Internet servers and its creation of the Java programming language. His observations, carried out in Sun's usability labs in Menlo Park, Calif., are teaching Nielsen and his colleagues the rules of effective communication on the Web. Nielsen shares those lessons in a biweekly Web column, "Alertbox," which is considered a must-read among usability engineers (www.useit.com/alertbox/). His latest book, *Designing Excellent Websites: Secrets of an Information Architect*, is due out this month.

Nielsen also travels widely, relentlessly advocating the cause of the beleaguered Web user. William Allstetter caught up with Sun's usability guru recently at the Human Factors & the Web Conference at the AT&T Learning Center in Basking Ridge, N.J.

TR: What are the defining characteristics of an unusable interface?

NIELSEN: It's difficult to learn. You get low performance even if you are an expert. You hate it. You make lots of errors. And you can't remember how to use it after you have been on vacation.

TR: And you think a lot of Web sites fit that description?

NIELSEN: Yes. The default on the Web is that people cannot use it. Jared Spool, founder of User Interface Engineering (www.world.std.com/~uieweb/) and an expert on interactive design, did an interesting study. He showed people a home page and asked them to find a specific piece of information that he knew existed

PHOTOGRAPHS BY ANNE HAMERSKY

on that Web site. But users succeeded in this task only 42 percent of the time.

TR: Why does the Web present such difficulties?

NIELSEN: I think the reason is that it is designed by people who don't understand interactive design. Most Web sites have never been tested on real users. Often, the only test is taking somebody into the art director's office to look at the screen. And that somebody is typically a vice president of marketing, who is thoroughly familiar with the company and so of course can understand the site design perfectly. But this is not a person who represents the general Web population.

TR: What are telltale signs that a site has been designed by somebody who doesn't understand interaction?

NIELSEN: Big blocks of text or big pictures are two dead giveaways. Another symptom is the absence of links.

TR: Are the wrong people doing Web design?

NIELSEN: That's part of the problem. Web sites are created by people in a company who are immersed in some project or business activity. They want to use the Web to communicate about what they're doing, but along the way, they seem to forget that their job is to convey information to people outside of their own circle. The problem is that once a person becomes familiar with a company's structure and lingo, it's very difficult to design an interface that will work for someone lacking that familiarity. It's like those *Where's Waldo* books—once you know where Waldo is, you can no longer pretend that you don't.

TR: How does this kind of inward thinking lead to bad site design?

NIELSEN: The classic mistake is to design a site based on the internal structure of the company, not based on how the user accesses the site. IBM's site is a good example. Say you own an IBM PC 300PL and you want to buy a compatible printer. If you go to the product page for the computer, you won't find any links to printers. That's because printers are made by a different division of IBM, and apparently no one bothered to link the printer pages to the PC pages. So you have to go all the way up to the IBM home page, or use the search button. Clicking on the "Assistant" button brings up a window that is supposed to help you find things. But the menu of products includes only ones from the division of IBM that designed the page you are on, not IBM's entire product line.

TR: How do you create a user-oriented Web site?

NIELSEN: You start with the users. That may sound like obvious advice, but most people don't follow it. Instead, they look at the Web as an opportunity to accomplish some goal of their organization. But that will only take you so far. If you are going to create a golf site, for instance, first find out what golfers want.

TR: How do you test usability?

NIELSEN: There are many phases to that. The most basic one is to get customers in our usability lab and have them sit and use the system. Direct observation is the best way of gaining usability knowledge and insights. We pay attention to facial expressions and body language and voice. It's just so painful to observe people make the same mistake again and again and again. That's where the observation really hits home.

TR: What commonly surprises Web-site designers when they watch users?

NIELSEN: Designers are taken aback to see users misinterpret interface elements that were supposed to be obvious. Users aren't stupid, but they are not in your company, and they do not understand your particular way of thinking, your vocabulary. Here at Sun, for example, we have something called Java WorkShop. In the early days, a lot of people would come across a link by that name and think, "Aha, this will be a Java training seminar." But that's not true—it's actually a piece of software. People who were looking for training would click on it, and people looking for programming tools would *not* click on it. Both types of users were fooled.

TR: What behaviors or characteristics do you see as being prevalent among Web users?

NIELSEN: People using the Web are impatient and very goal-driven; they always complain about anything that they perceive is slow. Also, they don't have a lot of tolerance for what you might call marketing speak or for companies that try to oversell to them.

TR: How about reading on the Web? Do people read differently on the Web than they do the printed page?

NIELSEN: This is one way the impatience shows itself. People don't read long blocks of text carefully or thoroughly on the Web. Screen resolution is too low, too coarse, so the letters don't feel smooth to the eye. That slows down the eye when it tries to read the text. So Web users tend to just scan sites, picking out the little snippets that are of interest to them.

TR: How should the writing and design of a site change to accommodate people who don't read?

NIELSEN: First, think how you would cover a topic in print—then cut the word count in half. People are not going to read every single word. Acknowledge that. Restructure the site to take advantage of hypertext.

TR: What are some specific principles to follow?

NIELSEN: It's important to specify what

Jakob Nielsen's Seven Deadly Sins of Web Design

Long download times. More critical than ever. You have 10 seconds before users get bored and leave.

Lack of navigation support. Don't assume users know as much about your site as you do.

Outdated information. Hire a Web gardener. Maintenance is a cheap way to enhance the content on your Web site.

Frames. They break the fundamental user model of the Web page. URLs don't work: You cannot bookmark the page and return to it.

Annoying animation. Mainstream users care more about useful content.

Orphan pages. Pages that lack logos, links or other hints to indicate what site they're part of. Always indicate what site the page is on and provide a link to the home page.

Long, scrolling pages. No longer a catastrophe, but still a problem. People don't like to scroll.

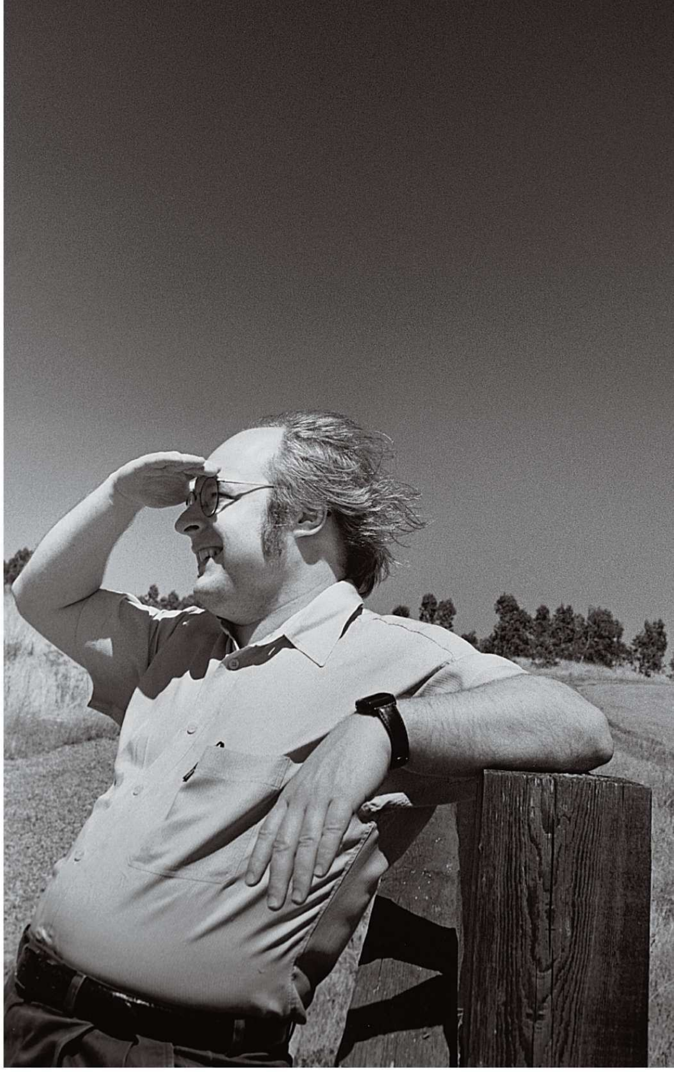
the page is about at the very beginning. People allocate very few seconds to deciding whether a site is of interest. If the good stuff is at the bottom of the page, the user may move on without ever seeing it. For the same reason, it's good to make heavy use of highlighted keywords—you want something that pops out as people scan down the page, something the eye can rest on. Also, you don't want to present a topic as one long, scrolling page.

TR: Some online publications break up articles into sequential chunks. At the bottom of each page it says, "Click here for the next page."
NIELSEN: I call that "page turning," and it's a truly bad solution to the problem of scrolling. It completely ignores what makes hypertext so powerful. You still have to go through these four pages in sequence. You can't jump to the one thing that you care about.

TR: What's a better way to handle long text, then?
NIELSEN: Make a brief introductory page that tells people very, very clearly what it is about. That page can be linked to a lot of sidebars and background information and other detail. If the links clearly tell which sidebars have what information, people can skip two-thirds of them and choose only the ones that are important to them. And linking to material from outside your own site allows you to take advantage of what others on the Web have produced. If you can select the correct links, you can enhance your service thousands of times beyond what you have the capacity to deliver yourself.

TR: The Web is a pretty unruly place, but you often harp on the need for structure. Why is that so important?
NIELSEN: A lot of Web sites don't have an information architecture—a structure—at all. They are just collections of pages that people lumped together on a Web site. Structure helps users navigate better by making it apparent at all times where they are on the site, where they have been, and where they can go. Structure also provides a clear underlying concept on which to map the diverse elements of a Web site. For example, if you are on a news-articles site with no structure, you say, "Okay, I am now reading article number 2,125." But how does that help you get to any other place on the site? How does it help you understand the relationship between this article and the previous one?

TR: In that example, what might you suggest?
NIELSEN: Well, you could add a timeline. Or you could divide the site into sections, like a newspaper—business, sports, whatever. You could provide the ability to sort through articles according to bylines. These kind of structural mechanisms make it much easier to deal with a vast pool of articles. Now there is one more point. You have to give the users what they say they want. But then you have to go beyond that and give them something extra. The Internet has to be better than reality.



You have to give users what they say they want. But then you have to go beyond that. The Internet has to be better than reality.

TR: What sites meet this test?
NIELSEN: I think that Amazon.com, the online bookseller, is better than reality in three ways. One, it is a bookstore that actually has every book. A physical bookstore can't do that. Second, for every book listed it also offers the titles of three other recommended books. Now, if you go to a regular bookstore, a knowledgeable staff will know good books to recommend. But they will know that only in a limited area of their expertise. At Amazon, they keep track of what people buy. People who bought the book you are looking at have also bought other books. You get a recommendation for the three they bought most frequently. Finally, Amazon.com sends out an e-mail message when the book has been shipped. It lets you know that in two days you will get the book you ordered. In the physical world, it wouldn't really make sense to send a postcard that says that your package is now in the mail, because the package and the postcard would arrive at about the same time.

TR: What usability improvements can help companies make money on the Web?
NIELSEN: A classic mistake to avoid is that companies make it difficult for people to buy online. They don't have the complete list of their products online. Also, they don't have descriptions of all the product variations. The Web allows you to have infinite detail. You can have all your products and all the obscure variations of those products online. So you can expand your sales dramatically just by making it easy for people to spend their money on your site. ◊

 By David Shenk

Stealing Calm: An Ode to Radio

Chances are, unless you've ever been alone in a radio booth, you have never experienced complete silence. I've had the privilege a number of times in the last few years, and have come to savor it. Whenever I'm scheduled to record a commentary or defend my point of view on a talk show, I try to show up a few minutes early just to bathe in the silence of the studio. Radio booths are generally cramped and are rarely much to look at—ratty carpet, corrugated walls (designed to nullify all sound waves coming from whatever angle), soft creakless chairs. But the stillness lends a cathedral-like quality. An unnatural calm slows down time. You can hear your own breath.

Of course, no one listens to radio in that kind of cocoon. We turn it on in the car, the backyard, the kitchen. But the silence of a radio booth says something important about the nature of the medium. As the delivery mechanism for a precious, fragile stream of audio, there is an uncompromising, almost militaristic component to radio's mission—that of vigilant protector. Seal the perimeter. Radio tightly focuses on a certain sound source to the rigid exclusion of all others. In a radio engineer's control room, there's a sanctity surrounding audio that you just don't see anywhere else in the media world. That's because with most other communications technologies, particularly anything with moving visuals, the task is not to slow down time, but to feed it as it ravenously marches forward.

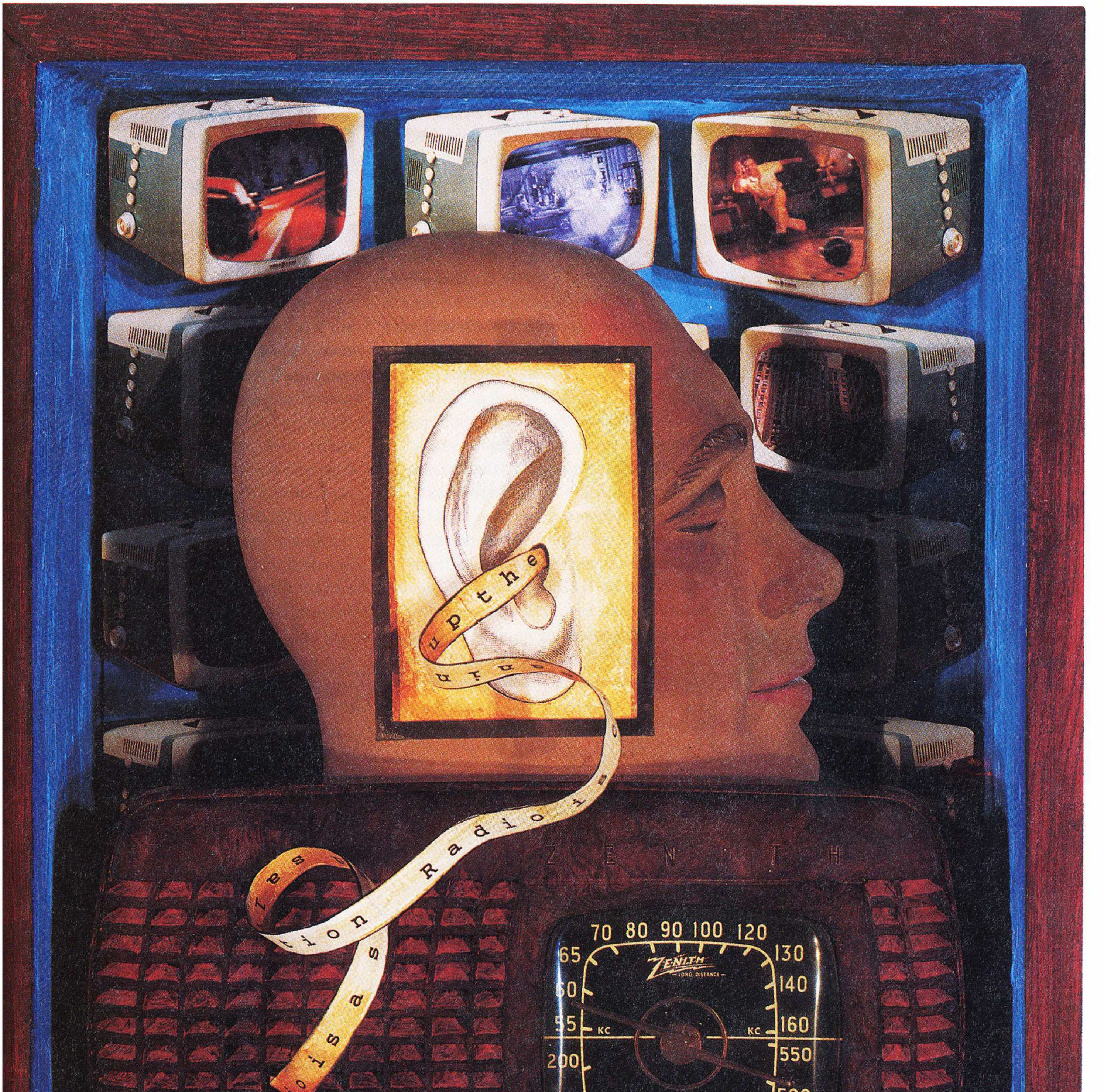
I've been thinking a lot lately about the difference between radio and multimedia, wondering how it is that such a technically confined medium seems to me so intellectually superior. How does radio, with its limited bandwidth and narrow one-lane avenue of sensory impact, triumph over the audio-visual feast of television and even the World Wide Web when it comes to conveying memorable information, provocative ideas and deeply human feeling? Marshall McLuhan wrote that radio "is really a subliminal echo chamber of magical power to touch remote and forgotten chords." I know I couldn't possibly count all the times, in 10 years of daily listening to a variety of programming on National Public Radio, that I have wept, had deep spiritual epiphanies, come up with provocative story ideas, or heard an idea or perspective that fundamentally changed the way I think about music or politics or language or science. But I do know that I owe a good bit of my life and career to what I've heard on shows such as "All Things Considered," "Fresh Air" and "A Prairie Home Companion," and I have spoken to many others who feel the same way. With no disrespect to the many serious and talented practitioners of commercial and public television, TV is regrettably not a medium that regularly nourishes the spirit or challenges the mind.

A comparison with TV is particularly instructive in light of the impending televisionization of the Web. The other day I was asked to appear on CNN*fn* for a brief discussion about the cultural implications of the failure of Panamsat's now-infamous Galaxy4 satellite. Always happy to plug my book, I ironed my shirt and found my way to CNN's New York studios, near Penn Station in midtown. The differences between TV and radio were much on my mind as I arrived at the 20th floor and began to notice that everything about the studio, from the makeup to the polished veneer set to the antiseptic dialog on the teleprompters, said: "Skim the surface." I wasn't there to truly discuss information proliferation; I was there to look the part of having a discussion about information proliferation, to mimic the type of discussions that might occur if the TV cameras weren't on. The audio would provide an appropriate backdrop for the image of the anchor and me speaking, looking into each other's eyes, exchanging penetrating remarks.

Radio booths are cramped and rarely much to look at.... But the stillness lends a cathedral-like quality. An unnatural calm slows down time. You can hear your own breath.

I did my seven minutes. It was, like the rest of the spots I saw that morning while I waited, unmemorable. I shook hands with the anchor, thanked him. Then, as I was heading away, a funny thing happened. One of the production assistants caught up to me and said, "Hey, interesting stuff, can I ask you a question?" We proceeded to talk for another seven minutes or so about computers, the Internet, Bill Gates and so on. It was about the same length as my conversation on air, and infinitely more interesting. It was an actual conversation, with a life of its own that couldn't have been charted in advance.

I don't fault the anchor or the producer for the drabness of the CNN*fn* conversation. I think the flaws are embedded in the video medium itself. There's an interesting paradox at



ZENITH
70 80 90 100 120
65 130
60 140
55 KC KC 160
200 550
225 500
250 300 400 450
METERS
MADE IN UNITED STATES OF AMERICA

work here: Moving images capture attention but subvert thought, a condition that is perhaps most vividly illustrated in the 1991 Wim Wenders film "Until the End of the World." Setting: It is 1999, and a scientist has just invented a camera that can record and replay not just images, but also the neurological recipe behind each image. It can enable the blind to see what sighted people see, or for anyone to replay their own dreams. Several characters in the film become hopelessly addicted to, and strung out on, an endlessly intoxicating video montage. The story is an elegy for our postindustrial society: a fragmented, alienated collection of individuals who seem to continually shift their attentions between flickering images—GameBoy, flashing billboards, news and stock tickers and so on.

Wenders calls this "the disease of images," the problem where "you have too many images around so that finally you don't see anything anymore." This in-your-face property of television becomes its defining characteristic for both producers and consumers. The inherently captivating and distracting properties of moving images allow—force—TV and its practitioners to constantly acknowledge and flaunt the primacy of images over ideas. It would seem as fundamental a natural law as paper-covers-rock or scissors-cuts-paper: Video trumps thought, complex thought anyway. Narratives work brilliantly on TV, of course, and the medium thrives on conveying primal feelings like lust, betrayal and triumph. There's something about the power of the moving image, though, that not only doesn't require much intellectual effort to consume, but actually discourages such exertion. *Sit back and let me come to you.* The vacant look in any TV viewer's eyes confirms this. So does the feeling we all have when we're a bit under the weather and just want to escape; we don't turn on the radio in those instances, or pick up a book. We watch TV. It's the great escape because it does all the work for us.

NOTICE THAT THERE IS NO analogous "disease of sounds." Sound moving in time is not inherently mesmerizing or captivating. It doesn't grab. To the contrary—the listener has to reach out with his or her attention and grab it, pull it in, and keep pulling with a considerable amount of focus. Television producers and Webmasters have learned to speed up images as a way of seducing people to refrain from changing channels. That doesn't work in radio. String together 90 split-second fragments of nonlinear audio in the same way that MTV does with video, and you'd see many unhappy faces.

Images captivate us effortlessly, and are difficult to filter out. Screening out sounds, though, is something that humans are well-constructed to do. It is very easy, we all know from experience, to lose focus on what someone is saying to you in a room, even when there is very little audio competition. And it's downright common to have the radio on and stop noticing its contents altogether. As soon as we stop pulling audio in, it fades into the background.

Being able to ignore radio so easily turns out to be the luckiest thing of all for the medium, because it also means that in order to really listen to it, we must become truly engaged. Radio won't "work" in the neural background. It won't settle for an intellectual glazing over. It requires more of a commitment, a certain level of consideration, concentration, rumination. And there's a direct payoff for the cerebral effort: Studies by the University of Califor-

Video trumps thought. What Wim Wenders calls the "disease of images" is all around us: We are bombarded by so many images that we don't see anything anymore.

nia, Los Angeles' Patricia Greenfield and colleagues show that radio inspires more imagination than television.

A healthy imagination and other aspects of creative thinking are the surest signs that we're pulling the information into our minds and interacting with it, that we're converting the information into knowledge. Kurt Vonnegut expressed this point marvelously in a recent magazine interview: "I can remember when TV was going to teach my children Korean and trigonometry," he said. "Rural areas wouldn't even have to have very well educated teachers; all they'd have to do is turn on the box. Well, we can see what TV really did....We are not born with imagination. It has to be developed by teachers, by parents....A book is an arrangement of 26 phonetic symbols, 10 numbers, and about 8 punctuation marks, and people can cast their eyes over these and envision the eruption of Mount Vesuvius or the Battle of Waterloo. But it's no longer necessary for teachers and parents to build these circuits. Now, there are professionally produced shows with great actors, very convincing sets, sound, music. And now there's the information superhighway."

Vonnegut's remarks suggest that electronic visual technologies have changed the rules of imagination. Historically, we have associated sight with understanding. "Of all the senses, trust only the sense of sight," Aristotle wrote in his *Metaphysics.* Our current language is loaded with words and phrases that analogize the two—"insight," "illuminate," "enlighten," "clarity," "observation," "brilliant," and so on. In an age in which more and more images are in motion, though, sight can neither be trusted nor counted on to propel us into thought and action. We're going to have to recalibrate our language and our thinking for a digitized age.

> *Historically, we have associated sight with understanding. Vonnegut suggests that electronic technologies have changed the rules of imagination: Sight cannot be trusted.*

FORTUNATELY, WE HAVE ABUNDANT text and audio resources at our disposal. We have the freedom to retreat to serious radio programming, to pull into the interior of our mind, to engage. The sanctity of audio allows for an intellectual intimacy that can be as nourishing as we allow it to be. None of these technological parameters ensure that a great percentage of radio programming will live up to the medium's potential—there's as much titillating mindlessness available on the radio dial as there is via the television remote or the Web browser. But it does set the bar high enough that an ambitious few will inevitably scale great

heights. I am chopping vegetables in my kitchen and listening to the first explanation of schizophrenia that has ever really made sense to me; now I am driving in my car listening to a very interesting conversation about beach erosion; now I am in the shower, really learning something about myths in Ireland. It's not just the quality of the information that's resonating with me; it's also the conduit. At its best, radio is at once formal and intimate, thoughtful and spiritual, visually confining and cerebrally expansive.

At CNN*fn*, I noticed that as I spoke informally with the production assistant, we mostly did not look at each other. We'd glance over frequently to make eye contact, to reinforce some point or some tonal cue. But most of the conversation itself was happening irrespective of the visuals—in spite of the visuals. We were intentionally avoiding a situation where our eyes would constantly be fed. On TV a moment before, it had been just the opposite. All conversation was made with lasting eye contact, perhaps the best clue of all that it wasn't a conversation but a visual simulacrum—a video painting—of a conversation.

ABOUT AN HOUR AFTER I left the CNN building, I was in a radio studio on 56th Street near Sixth Avenue, participating in a wonderful public radio show called "The Connection," hosted by Christopher Lydon. For about an hour, a handful of people on the show shared observations and ideas, spoke with their eyes metaphorically closed, making a psychic connection. Real thoughts were formed, articulated, considered. As I listened to thoughtful guests and the callers who responded to them, I wondered: Is any technology more "interactive"? It wasn't a perfect hour. I stumbled a bit, said some things I wished I'd said better. But it was still a terrific conversation. Callers thanked the host for another marvelous program, and you could hear that they meant it. People weren't just listening because they had time to kill. They were engaged. This wasn't entertainment; it was nourishment.

After the show, I stuck around the studio for a few precious minutes to let the ideas settle a bit, and to steal just one more moment of calm. TR

Miracles of Saint Judah

One of the more amusing aspects of the recent flurry of stories about two promising new cancer treatments is the way researcher Judah Folkman, the son of a rabbi, has been hailed as a secular saint—even though all his miracles, as he's the first to admit, have taken place in mice.

Hardly a week had passed after the now-notorious May 3 front-page story in *The New York Times,* which described the work of Folkman's lab at Children's Hospital in Boston on endostatin and angiostatin, before Folkman was canonized. As the noted molecular biologist Yogi Berra once observed, "It's déjà vu all over again."

Anti-angiogenic factors work by blocking the formation of new blood vessels to tumors, essentially starving the cancer. Last November, Folkman's group reported in *Nature* that repeated courses of one such agent, endostatin, cured three different kinds of implanted tumors in mice.

Since we live in an age when the fate of a few genetically challenged rodents can send shivers through the stock market, revisiting the scene of this crime for a moment affords an opportunity to reiterate a few obvious points about biotechnology, the press and the public. With apologies to Wallace Stevens, here are Five Ways of Looking at a Breakthrough.

Hardly a week had passed after the now-notorious New York Times story before Folkman was canonized.

■ **The Magic Bullet Syndrome:** We've all been spoiled by penicillin, a magic bullet the likes of which we'll probably not see again in our lifetime. Every few years, however, a new cancer treatment heads into the clinic with the kind of buildup more suitable to Hollywood than to Harvard. Connoisseurs of this form of hopeful hype will recall the examples of interferon (heralded by a cover story in *Life* in 1979), interleukin-2 (cover stories in *Fortune* and *Newsweek* in 1985), monoclonal antibodies (another *Fortune* story in 1987), tumor necrosis factor, shark cartilage...you name it. Between IPOs and voracious news cycles, every dog of a molecule has its day in the biotech business.

■ **The Salk Complex:** This is a special concoction of the press and the lay public. We like our breakthroughs to be singular, the product of soloists or divas or maestros. If they've struggled mightily upstream against the tide of Conventional Wisdom, all the better for the story line. Jonas Salk's polio vaccine, the model of 20th century scientific heroism, arrived at a unique moment of American innocence, optimism and gratitude, but you saw some of the Salk treatment in the Folkman coverage, especially in the suggestion that scientists used to snicker at angiogenesis as an approach. I heard plenty of laughter when I sat in on a Folkman talk not long ago—but only because he has such a great sense of humor. In fact, any narrative that depicts the scientist as a lone wolf hero ignores the reality that science is a collaborative, synergistic, community-driven enterprise.

■ **The Brilliant Lab Chief:** As beloved as Judah Folkman is in the world of molecular biology, his lab is no different than others. He handles the High Concept scientific approach and brings in the dough, but others—usually postdocs and fellows—provide the elbow grease that turns pipe dreams into peer-reviewed papers. If endostatin ever becomes a major drug, Michael O'Reilly, a research fellow in Folkman's lab who isolated the molecule, deserves a lot of credit. In his talks, Folkman amply and wittily acknowledges the contribution of O'Reilly and others. But these collaborative subtleties generally don't find their way into the news stories.

■ **There Are Always Other Ways to Skin a Cat:** EntreMed Inc., the biotech company holding the rights to angiostatin and endostatin, made the usual bottle-rocket run on Wall Street on the basis of the initial press coverage *without having made, much less tested, the drugs under study.* Meanwhile, many other companies have anti-angiogenesis factors in clinical trials.

Among these other companies are Agouron Pharmaceuticals, Imclone Systems, Sugen and Magainin Pharmaceuticals. They all have promising agents in trials, but you wouldn't know that from reading the stories about Folkman's work.

■ **The Lazarus Bullet:** Many agents that begin as "magic bullets" subsequently lose much of their luster—as endostatin may do. But some of those old, discredited magic potions subsequently rise from the dead. Since the endostatin story exploded in early May, the Food and Drug Administration (FDA) has recommended several of them. At the end of May, an FDA advisory panel recommended approval of a monoclonal antibody that counteracts the effects of tumor necrosis factor in Crohn's disease. Several days later, a form of interferon received approval for the treatment of chronic hepatitis C in combination with a second antiviral drug. Neither of those treatments represent cures; they represent incremental improvements in care.

But that, in the end, may be the real story of magic bullets. They're hardly magic, but given enough time and experimentation, they often *do* work as bullets. And in the war against an enemy as tough as cancer (not to mention many other diseases), perhaps the most important thing is to have a little ammunition that works, rather than the perfect ordnance which, like magic, is illusory. ◊

REVIEWS BY WADE ROUSH

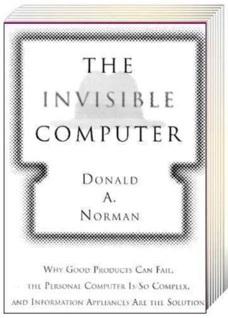
They've Really Got a Hold on Us

SOME MEN SEE MAchines as they are and ask, "Why?" Donald Norman dreams of machines that never were and says, "Why not?" Actually, in this new book on the need for successors to the personal computer, Norman pursues both questions. And he answers them with the same wit, perceptiveness and prophetic zeal that made his 1988 book *The Psychology of Everyday Things* a minor classic.

Norman is a prominent expert in behavioral design, the art of creating tools that mesh well with their users. Well-designed objects, he teaches, require no special effort in order to be understood and operated. They do their jobs without calling attention to themselves. They make work efficient, even pleasurable.

Today's personal computers, Norman argues, do none of these things. Instead, they regularly make their owners feel stupid, helpless and subservient. Today's Macintosh- and Windows-based computers are immensely versatile, Norman grants, but when features and functions multiply to the point that the operating system is bigger than any of the applications it manages, frustration is the inevitable result. "Making one device try to fit everyone in the entire world is a sure path towards an unsatisfactory product," he writes. "Either it will fail to accommodate the critical needs of some of its intended users, or it will provide unnecessary complexity for everyone."

The problem, Norman believes, is that computer builders are arrested adolescents who think customers love new technology as much as the designers do and are equally willing to endure the inevitable inconveniences. But the majority of consumers, he argues, are conservative "late adopters" who demand reliability and ease of use. Technologies that do not mature to meet these demands must fail.



THE INVISIBLE COMPUTER: Why Good Products Can Fail, the Personal Computer Is So Complex, and Information Appliances Are the Solution
by Donald Norman
MIT Press, 298 pp., $25

The solution to the PC's daunting complexity, Norman argues, is to expand the new class of "information appliances," each good enough for one purpose, but each made powerful by its ability to share data with other appliances. The digital camera, for example, could evolve into a general "image gathering device" that uses its data port as well as its lens to collect pictures, and transmits those pictures to printers, studios, storage devices, television displays or the Internet. But this part of the discussion is less persuasive than Norman's critique of the PC. Smart appliances will have to mature before people will sacrifice the investment and learning time they've poured into their PCs. These capricious machines have a hold on us yet.

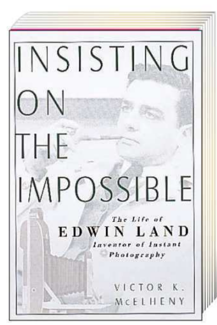
Impatience Is Also a Virtue

WHAT HAPPENS TO THE SPARK OF greatness many 18-year-olds have when they arrive at MIT, Harvard, Caltech or Stanford? For most, Edwin Land once said, it is extinguished by undergraduate education's preoccupation with "questions to which the answers are known." The message in all those lectures and exams, he feared, is that the "secret dream of greatness is a pipe-dream; that it will be a long time before [a student] makes a significant contribution—if ever."

Land's unwillingness to wait helps explain why he dropped out of Harvard (twice) and, at the age of 24, earned the first of his 535 U.S. patents on the manipulation of light. It may also explain his interest in instant cameras, born one day in 1943 when his equally impatient young daughter, whose picture he had just taken, asked why she could not see it right away. What is certain is that Land's irreverence toward received wisdom helped him to build a unique empire of invention, the Polaroid Corp., and to transform the way his contemporaries thought about not one, but three momentous subjects: photography, nuclear-age military reconnaissance and the biology of color vision.

Unfortunately, the inventor did much to discourage biographers, rarely granting interviews during his 81-year lifetime and arranging for his papers to be shredded after his death in 1991. But he has been skillfully thwarted by Victor McElheny, a distinguished science journalist who followed Land's career for decades. (In the interest of full disclosure: McElheny is a member of *Technology Review*'s board of directors and was a dissertation advisor to this reviewer.)

Like the spy planes and satellites Land helped develop in the 1950s and 1960s, McElheny has both a broad field of view and an acute eye for detail. He documents, for example, the importance of the science advising apparatus that arose during the Eisenhower administration and Land's little-known part in it. A crucial question in 1954 was the strength of the Soviet bomber force, and Land was convinced that a high-altitude spy plane carrying thousands of feet of film could be built to answer it. He helped overcome Air Force resistance to the idea, and far from heightening Cold War tensions, McElheny argues, the U-2 aircraft that resulted gave Eisenhower the information he needed to deflate the Pentagon's fears of Soviet superiority and to slow the arms race.



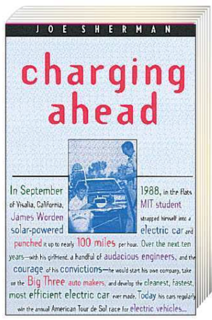
INSISTING ON THE IMPOSSIBLE: The Life of Edwin Land, Inventor of Instant Photography
by Victor McElheny
Perseus Books, 512 pp., $30

But McElheny dwells with equal thoroughness and passion on the ingenious chemical tricks Land and his

co-workers devised so that exposed negatives could create their own positives without darkrooms, wetness or a wait. Gripped by such a technical challenge, McElheny relates, Land could go for days without leaving his laboratory. His mottoes were "Never go to sleep with a hypothesis untested" and "Every problem can be solved with the things in the room at the time." The ultimate secret of Land's greatness, McElheny's excellent book implies, was that a question only interested him if its answer was unknown.

Amateur Entrepreneurs

BACK IN 1994, SOLECTRIA was the Netscape of the auto industry, a whiz-kid-led company whose light, advanced-composite electric vehicles were challenging Detroit and the reign of the internal-combustion engine. The challenge seemed real, because California's zero-emission vehicle (ZEV) mandate—requiring that 2 percent of all new vehicles sold in the state after Dec. 31, 1997, emit zero pollutants—promised to give the market for clean electric cars a big jump-start.



CHARGING AHEAD:
An Electric Car That Goes the Distance
by Joe Sherman
Oxford University Press, 256 pp., $24.95

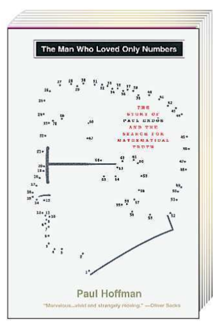
But 1998 is here, and very few of the cars one sees in California are Solectrias. Why? Is it because unfair lobbying activities by the big automakers led to the elimination of the ZEV mandate in 1995? Or because Solectria didn't have the know-how or resources to scale up its manufacturing process quickly? Or because gasoline-powered cars still outpace electric cars in safety, convenience and affordability?

All these causes and many more appear to be at work in *Charging Ahead,* a sympathetic yet faultfinding history of Solectria's coming-of-age. As author Joe Sherman tells it, MIT mechanical engineering student James Worden and the friends who followed him to Solectria in 1989 were at heart technology enthusiasts, not environmentalists or sophisticated entrepreneurs. Worden had started building electric cars as a teenager, and the ZEV mandate, also adopted by several states in the Northeast, meant he might profit from his passion. Solectria's sleek prototypes won several racing tour victories in the early 1990s, persuading powerful partners such as Boston Edison and the Defense Advanced Research Projects Agency to chip in. For a few years, it seemed that the time had finally come for a car that could be recharged rather than refilled.

But by 1995, when the first Solectria Sunrise rolled, the mandates were being dismantled, Solectria's partners were getting frustrated with Worden's controlling management style and the lack of a manufacturing plan, and the big automakers were debuting their own electric cars. Today, Solectria sells Sunrises and electric vans and pickups in low volume, but, to Sherman's disappointment, the company and the industry still haven't gotten out of first gear. He blasts the "Big Boys," the major automakers, for allegedly mounting disinformation campaigns that swayed politicians and the public against the ZEV mandates. But other incidents in the book—such as Worden's trip to the intensive care unit after bromine vapor from a leaky battery engulfs his race car—make it clear that electric vehicles, and the companies that build them, still have some maturing to do.

What Is This White Stuff?

BEFORE PAUL HOFFMAN came along, Paul Erdös was famous only among mathematicians. Erdös (pronounced air-dish) was an impish, amphetamine-swallowing number theorist from Hungary who lived out of a shabby suitcase, gave nearly every waking moment to mathematics and published more than 1,400 papers, making him one of the most prolific mathematicians of all time. Colleagues in dozens of countries adopted him as their itinerant "Uncle Paul" and saved up their thorniest math problems for his visits. But after Hoffman profiled him in *The Atlantic,* Erdös' renown grew logarithmically, so much so that *The New York Times* felt obliged to run a 1,200-word obituary on his death in 1996.



THE MAN WHO LOVED ONLY NUMBERS:
The Story of Paul Erdös and the Search for Mathematical Truth
by Paul Hoffman
Hyperion Books, 302 pp., $22.95

Erdös was the kind of subject magazine writers kill for: brilliant and eccentric, with a colorful history and a penchant for advertising his irreverent philosophy of life. But to evoke in readers the same mixture of amusement and awe Erdös' colleagues felt toward him, while simultaneously explaining Erdös' lifelong love for numbers, required a writer with Hoffman's special literary and intellectual skills.

(Ironically, Hoffman's book isn't the only one on Erdös coming out now. A second book, by Bruce Schechter, My Brain Is Open, published by Simon & Schuster, includes many of the same stories but covers more number theory. Schechter, a science writer with a PhD in physics, writes less alluringly than Hoffman but provides extra background for readers who may crave more mathematical meat.)

Hoffman's book, based on the Atlantic article, is structured around anecdotes from Erdös' peculiar life, but it is less a biography than a highly successful popularization of number theory and its history. Comical passages describing Erdös' eccentricities such as his amnesia for everything nonmathematical (every time he was served rice he had to ask what it was) are plentiful, but they serve primarily as interludes.

In the book's main passages, Hoffman takes forbidding mathematical issues related to Erdös' work and explains them with lucidity and infectious pleasure. Having read this I think I comprehend for the first time why it's always better to switch doors in the Monty Hall dilemma, and why the counting numbers increase to infinity but the supply of real numbers and transcendental numbers such as e and π is infinitely larger than this infinity. If "mathematics is the only infinite human activity," as Erdös liked to say to explain his own interest in numbers, then it's lucky we have people like Hoffman to make it a little more finite for the rest of us. ◊

World Wide Words

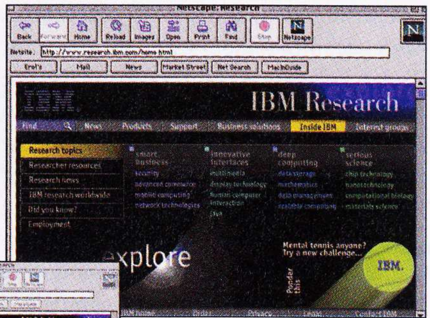
The industrial research labs are the mother lode of innovation, right? Then how come their Web sites are so lame? **By Herb Brody**

A TYPICAL RESEARCH LAB CAN BE A letdown for a nonscientist. There's very little Mr. Wizard stuff: bubbling test tubes, flashing laser beams. Much of what's there goes on inside pieces of nondescript equipment with readouts that look about as high-tech as a microwave oven. Nonscientists often emerge from lab tours baffled and bored.

The Web, on the other hand, would seem to give research organizations a chance to counteract this drab PR by letting them strut their stuff to the public in a friendly, engaging way. Bells, whistles, interaction!

To find out whether labs are really making use of all this potential—and to keep in step with this issue's special focus on research-oriented organizations—we took a gander at an assortment of sites. Unfortunately, the Web sites aren't really much more stimulating to look at than the labs themselves. It's as if these labs expend all their creative energy giving the world new tools and knowledge; nothing is left at the end of the day to provide casual Web visitors with more than the most superficial of insights into the fascinating stuff we know the labs are really doing.

Take General Electric's corporate R&D center in Schenectady, N.Y. Its Web site (**www.crd.ge.com**) has all the pizzazz of a burned-out light bulb. A page recounting the century-old lab's inventions blows a huge opportunity by supplying no links to information about current work that follows from these pioneering efforts. Thus you read that in the 1960s, GE scientists invented the process of superconductive tunneling, but you have no quick way of learning about any practical applications that the intervening decades have brought.



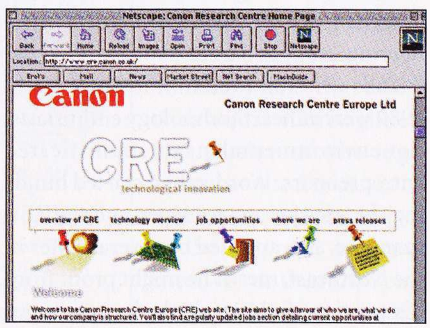
But GE might not be a fair test—the company makes no particular claim to be on the information cutting edge. So we checked out the site of another huge company that does make such boasts for itself: IBM. The giant computer maker is justly proud of its research operation, which has brought the world advances in integrated circuits, superconductors and magnetic disk storage, among other things (*see "The Big, Bad Bit Stuffers of IBM," TR, July/August*). And a visit to **www.research.ibm.com** reveals a well-organized showcase of the company's R&D. Information is presented in small chunks, under headings like "Smart Business," "Innovative Interfaces" and "Serious Science." Captured under these headings are a tasty assortment of quick vignettes describing activities at the company's labs around the world.

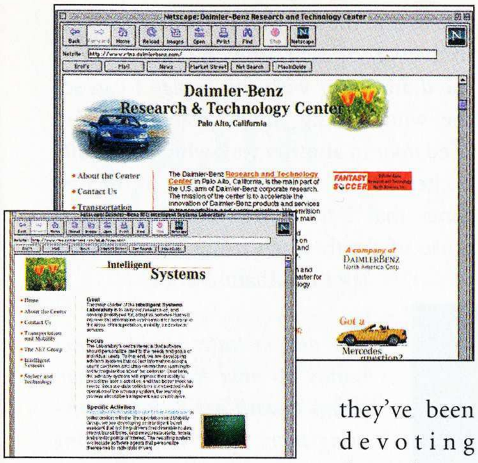
The IBM site's appeal, unfortunately, is only skin deep. I tried to explore what IBM had going on in display technology (that's under "innovative interfaces"), and found only a series of *all-text descriptions.* A tantalizing link called "how it works" merely delivers a few more sentences, again without a visual aid that a Web page could so readily supply. Clicking on the name of a technology area brings up a paragraph or two of text, unadorned by any helpful visuals. This is a site produced by a company built on skillful marketing of technology to business? What do the folks at IBM think WWW stands for? World Wide *Words?*

At least GE and IBM have some content, even if it's dry. I hop over the virtual Atlantic to visit the Canon Research Centre Europe in Surrey, England (**www.cre.canon.co.uk**), and click on "Press Releases," hoping to find out the latest doings in the company that gave the world cheap laser printers, among other technologies. The response: "We have a lot of exciting projects in the pipeline. Please return to hear the latest news." Yes, I know that the Web is perpetually "under construction," but surely Canon can think of something to tell us while all that excitement trickles down the pipeline.

Now I'm getting desperate. Surely, I think, I'll get a knock-your-socks-off display of technical prowess from Daimler Benz, the company whose cars are emblems of engineering excellence. But the Daimler-Benz Research and Technology Center site (**www.rtna.daimlerbenz.com**) limps along like an underpowered VW. I click on the link for the company's Intelligent Systems Laboratory and am treated to standard corporate R&D rhetoric: the lab's mission is to develop software to "personalize itself to the needs and goals of individual users." This would lend itself wonderfully to online demos, I'd think, or at least graphical demonstrations. But again, we're in logorrhea-land—buried in words without a link to escape by.

After spending several online sessions bouncing from one research site to another, I land at a couple that at least attempt to exploit the Web's dynamic nature to help present information. I find this relief in a most unlikely place: the federal bureaucracy. The national laboratories have, in fact, gotten in the spirit of things. The labs that invented nuclear weapons know that bomb-making is not a growth industry;





they've been devoting themselves to moving their other technical know-how into the private sector, and they've become pretty slick at it. The Los Alamos National Laboratory, for instance, uses a Java applet to illustrate a new technique for sensing degradation in concrete: wave the pointer over a photo of concrete and the image turns colors to help explain the problem the new technology solves.

That's a B+ for effort, but another Department of Energy facility—The National Renewable Energy Laboratory (**www.nrel.gov**)—does much better. Its site provides a well-written tutorial about photovoltaic cells, featuring a nifty animated graphic. If a picture is worth a thousand words, then moving pictures are worth—well, let's not get metaphysical. Let's just say it helps a lot, and it's the kind of Web technology that is almost entirely lacking at other R&D sites.

A research-oriented Web site doesn't need graphical sizzle to provide great value, though, as I discovered from visiting the Community of Science's site. Here are searchable databases listing projects sponsored by funding agencies, such as the National Institutes of Health and the National Science Foundation. (It's at **http://fundedresearch.cos.com**—no *www*). Just type in key words, names of investigators, or the identity of an institution, and you get a quick list of project titles, each linked to an abstract and a second form that lets you refine the search. There's nothing flashy about it, just a huge amount of information in a handy, easy-to-reference site.

Perhaps it's not surprising that the R&D folks that built the Internet in the first place tend to lag behind the curve in innovative use of it. Pioneers don't stick around to make the lawns look good—they move on to discover other territories. TR

A Rare Sight

Elizabeth Goldring looks for art and gets an eyeful

Poet and artist Elizabeth Goldring's eyes fill with light when she works—laser light, that is. A degenerative eye disease damaged Goldring's vision, so she must go to great lengths to see her own art; she uses a laser to project the video and computer images she creates directly onto a small, functional part of her retina.

The device that brings Goldring's work back into her view is a modified version of a diagnostic tool called the scanning laser ophthalmoscope (SLO). By connecting the SLO to cameras, computers and even the Internet, Goldring can see friends' faces, unfamiliar buildings and—for the first time in years—words. With help from the SLO's inventor and other researchers, students and artists, Goldring hopes someday to use the machine to share visual experiences with others she believes have been encouraged unnecessarily to "turn off their eyes."

JOHN SOARES

Steady gaze: Goldring melds art and technology to redefine vision.

But, as *TR* Associate Editor Rebecca Zacks discovered when she visited Goldring at MIT's Center for Advanced Visual Studies, seeing with the SLO is an intense and tiring experience. And even with the device, Goldring's vision is too poor to read traditional text. So Goldring is developing a terse visual language of "word-images," hybrids of letters and graphics that make intuitive and immediate sense.

Without the SLO, Goldring sees faces only as "moons," but her gaze is steady as she speaks:

For the last seven years, I've been working on creating visual experiences and digital language—poetry—for people who have very limited eyesight. Before that, for close to four years, I saw virtually nothing: some light, some shadow perception. When my eyesight began to deteriorate, I spent a lot of time writing about it—both poems and "eye journals" describing what I saw as I looked out of damaged eyes. I had to try to figure out how to write with a tape recorder, and it's really difficult for a writer to write without seeing any words.

Goldring points out a poster on the wall that shows a word-image—a simple outline of a door flanked by the letters d *and* r*—projected onto the veined surface of a human retina.*

Images from a scanning laser ophthalmoscope have a really indelible quality. It's almost as though your retina is a stone and the image is carved in by the laser. This is a healthy retina looking at a word image that I've created: *door*. I've worked a lot with this particular word because it's so difficult for me to see—the two *o*s and the *d* are all so similar, they get in the way of each other. But if I separate the *d* and the *r* with this image I can see the whole thing much faster. I've also tried *door* in another way, which I'm quite excited about because it is one of the first times that I have been able to get any sense of depth when using the scanning laser ophthalmoscope.

She demonstrates, holding her hands up next to one another, palms toward her face, and pivoting them apart like swinging saloon doors.

The word opened: *d-o* and *o-r* swung back like a door, and it worked because it was separating the *o*s. It also worked spatially and it enhanced the meaning of the word so that you get it instantly. Bad seeing or significant visual impairment means, among other things, very slow seeing. So anything you can do to convey the meaning faster helps. When people with normal vision read words, they scan across the tops of the letters. Well, I don't—I have to look around, up and down each letter. By the time I get to the end of a three-letter word, I have put in a great deal of effort. That's why I'm interested in developing succinct symbols.

After years spent creating words, poems and video images for the SLO, Goldring believes she's "on the brink" of being ready to show her work to other visually challenged people.

For people to want to use eyes that don't work very well, they will have to have compelling visual images. That's really what I'm working on, not only with language but also other kinds of visual experiences. I think the ways in which people see what's being presented will need to be individualized: Some people may need the laser brighter, some people may need it dimmer. In the case of word images, some people may need curves, others may need hard edges. I don't think this individualized tailoring is difficult. The hard part is getting something that is compelling enough and satisfying enough to warrant the extreme amount of energy and dedication it takes to look. ◊

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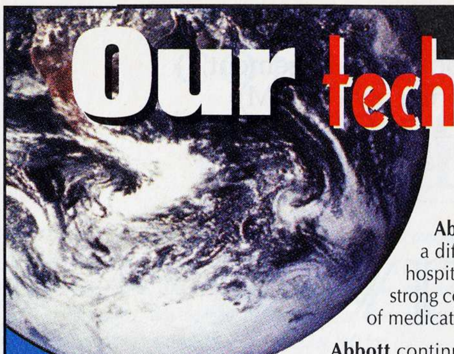

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The Original Duplicator

In Astoria, Queens, Chester Carlson did the first Xeroxing

Sixty years have passed since the first time anyone performed a task that's now done millions of times an hour: making a xerographic duplicate. With that first copy, a shy bespectacled inventor named Chester F. Carlson inaugurated a technology that each day gives untold numbers of office workers instant gratification. Carlson's gratification as an inventor, on the other hand, required decades of patience.

Raised in poverty, Carlson earned a physics degree from Caltech in 1930. In the depths of the Great Depression, he couldn't find work in physics; by 1934 he was submitting patents for a New York electronics firm by day and going to law school at night. The tedium of copying patent and legal material by hand bred in Carlson an obsessive desire to invent a cheap and easy method of duplicating documents.

Carlson pored over journals, mentally combining well-known physical principles into a process he called electrophotography. He first experimented in his kitchen, but the noxious fumes irritated his neighbors, so Carlson retreated to an Astoria, Queens, apartment owned by his mother-in-law. There, on October 22, 1938, he tested the complete process. He projected an image onto a positively charged metal plate. Where the light hit (the white areas of the image) the charge drained away. He dusted negatively charged toner powder across the plate, which stuck selectively to the dark areas of the image. He blew away the extra toner, and the plate was ready to print a copy onto positively charged paper. The world's first electrophotographic image read simply "Astoria, 10-22-38."

Though a tenacious tinkerer, Carlson was no salesman; it wasn't until 1946 that the Rochester-based Haloid Company agreed to develop an electrophotographic machine. Haloid renamed Carlson's concept "xerography"—from the Greek *xeros* for dry and *graphein* for writing or drawing. In 1960, Haloid-Xerox (soon to be Xerox) introduced the 914 copier, the first push-button, plain-paper, xerographic office machine.

The 914 revolutionized the workplace and brought its inventor fabulous wealth, but the father of fast document duplication preferred life in the slow lane. He lived modestly and, by the time of his death less than a decade later, had donated almost $100 million to causes ranging from Caltech to the promotion of Zen Buddhism. ◊

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